DRAFT
MERCURY REPORT

Department of Toxic Substances Control

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Hazardous Waste Management Program
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Definition of Acronyms and Abbreviations

$\mu g/m^3$	microgram per cubic meter
$\mu g/L$	micrograms per liter
22 CCR	Title 22, California Code of Regulations
AB	Assembly Bill
AB 1807	Toxics Air Contaminant Program
AB 2588	Air Toxic "Hot Spots" Program
APCD	Air Pollution Control District
AQMD	Air Quality Management District
ARB	California Air Resources Board
ATSDR	Agency for Toxic Substances and Disease Registry
CEIDARS	California Emission Inventory Development and Reporting System
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CH_3Hs	Methyl mercury
CIWMB	California Integrated Waste Management Board
CTR	California Toxics Rule
DHS	Department of Health Services
DTSC	Department of Toxic Substances Control
Hg^0	Elemental mercury, metallic mercury, quicksilver
HgS	Inorganic (oxidized) mercury
HID	High Intensity Discharge
HPSuL	High-Pressure Sulfur Lamps
HSC	Health and Safety Code
IRIS	Integrated Risk Information System
LOAEL	Lowest Observed Adverse Effects Level
LPSL	Low-Pressure Sodium Lamps
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
mg/kg/day	milligram per kilogram per day
mg/L	milligrams per liter
MRL	Minimal Risk Level
MSW	Municipal Solid Waste
NAS	National Academy of Sciences
ng/g	nanograms per gram
ng/L	nanogram per liter
ng/m^3	nanogram per cubic meter
NOAEL	No Observed Adverse Effects Level
NPL	National Priorities List
OEHHA	California's Office of Environmental Health Hazard Assessment
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PHG	Public Health Goal
POTW	Publicly Owned Treatment Works
RCRA	Resource Conservation and Recovery Act

RELs	Reference Exposure Levels
RfC	Reference Concentration
RfD	Reference Dose
RWQCB	Regional Water Quality Control Boards
RWQCP	Regional Water Quality Control Plant
San Francisco Bay TMDL 2000 Report	Abu-Saba, et al., *Watershed Management of Mercury in the San Francisco Bay Estuary: Total Maximum Daily Load Report to U.S. EPA*, June 2000
SARA	Superfund Amendments and Reauthorization Act
SB	Senate Bill
SB 25	Children's Environmental Health Protection Program
SIC	Standard Industrial Classifications
SNARLs	Suggested No Adverse Response Levels
SWAT	Solid Waste Assessment Test
SWRCB	State Water Resources Control Board
TAC	Toxic Air Contaminant
TCLP	Toxicity Characteristic Leaching Procedure
TMDL	Total Maximum Daily Load
TTLC	Total Threshold Limit Concentration
U.S. EPA	United States Environmental Protection Agency
USEPA 1992 Study	U.S. EPA 1992. *Characterization of Products Containing Mercury in Municipal Solid Waste in the United States, 1970 to 2000*
USEPA 1997 Study	U.S. EPA 1997. *Mercury Study Report to Congress*
USGS	United States Geological Survey
USGS 2000 Study	United States Geologic Survey, June 2000
WET	Waste Extraction Test
WMUD	Waste Management Unit Database

Executive Summary

This report examines the problem of mercury contamination in California's environment and the contribution of the disposal of mercury-containing waste not currently regulated as hazardous waste. The report consists of six sections. The first provides a general overview of California's mercury problem, while each of Sections 2 through 5 focuses on a different aspect of mercury in more detail. The final section examines several options for reducing the further contamination of California's land, and recommends changes to the State's criteria used to classify mercury-containing waste as hazardous waste.

Section 1 provides a general overview of mercury in the State's environment. Mercury is a metal that occurs naturally in California, and its use has been and continues to be widespread throughout the world. As a result, mercury contamination is found throughout the State, in all environmental media. This widespread contamination is especially serious because of mercury's unique combination of properties.

Because metallic mercury is a liquid at room temperature, it is especially mobile in the environment. It is also persistent in the environment, and forms organomercuric compounds that can bioaccumulate in organisms and biomagnify in the food web. High-level predators can have mercury body burdens that are several orders of magnitude higher than the concentrations found in the surrounding environment. Environmental mercury can readily move among environmental media. For example, mercury that is emitted directly to air is inevitably deposited on land and water. Similarly, mercury contained in waste that is deposited in municipal landfills can dissolve in landfill leachate and potentially contaminate the State's waters.

Mercury's health and environmental hazards have led to the development of numerous regulatory standards for mercury in waste, air, and water, as well as occupational exposure standards. These standards have been exceeded in some cases, necessitating action by responsible parties, as well as State and federal agencies. A number of sites in California are sufficiently contaminated with mercury to make clean-up or other mitigation activities necessary. Similarly, some of the State's water bodies exceed water quality standards for mercury, triggering a requirement under the Federal Clean Water Act that Total Maximum Daily Loads (TMDLs) be developed. Sport fish in certain of State's water bodies are sufficiently contaminated with methylmercury that the Office of Environmental Health Hazard Assessment (OEHHA) has advised the public to restrict or eliminate consumption of them.

Under current hazardous waste identification criteria, some mercury-containing waste is sometimes classified as nonhazardous waste, and consequently, it legally may be disposed in municipal landfills. While the mercury concentration in such waste is relatively low, the large volume of waste that is disposed contributes a significant amount of mercury to municipal landfills. Studies have shown that municipal landfills can leak detectable concentrations of mercury and, in a recent study, various mercury species were found in municipal landfill gas.

Section 2 describes mercury's chemistry and toxicology. Three important forms of mercury exist in the environment: metallic mercury, mercuric mercury, and methylmercury. Each has distinct chemical and physical properties, environmental behavior, and toxicology. Mercury's environmental fate and transport are described in terms of flux or movement between environmental media. Up to 75 percent of the mercury emitted to the world's atmosphere is of anthropogenic origin, and the world's atmospheric mercury load has increased between two and five-fold since industrialization.

Atmospheric mercury is ultimately deposited on land or water, either in precipitation or via dry deposition of particulates. Of the environmental media, mercury is least mobile in soil. However, mercury can form soluble complexes with organic ligands in soil, and subsequently dissolve in runoff or leach from municipal landfills. Mercury that enters marine environments can be methylated by both biotic and abiotic processes. It can enter the marine food web via plankton in the water column and via larger invertebrates in marine sediments.

Eighty percent of inhaled elemental mercury is absorbed into the body. Neurotoxic effects are the most sensitive toxicological endpoint of elemental mercury. They include tremors, changeable emotional state, insomnia, headaches, sensory loss, memory loss and impaired cognitive function.

Mercuric mercury enters the body via inhalation, ingestion, or dermal exposure, and can be methylated by gastrointestinal microbes. Renal toxicity is the most sensitive toxic endpoint in humans.

Methylmercury can be absorbed by the lungs and is well absorbed in the digestive tract. Humans absorb 95 percent of the methylmercury in the fish they consume and lipophilic and readily crosses the blood brain and placental barriers. Methylmercury's half-life in blood is estimated to be 50 days and is a potent developmental and neurological toxin in humans.

Inorganic and elemental mercury are both toxic, but of the environmentally important forms, methylmercury poses the greatest risk to human health and the environment due to its high toxicity and the fact that it bioaccumulates in aquatic organisms. Consumption of contaminated fish is the primary route of human methylmercury exposure in humans.

Section 3 discusses the sources of mercury in California's environment. The mercury in the State's environment originates from both natural and human sources. Both historical and ongoing sources have added to California's current environmental mercury burden. Important historical mercury sources include gold and mercury mining and past waste and industrial management practices, such as open garbage burning; and the collection of industrial process wastes in unlined sumps, ponds, and lagoons. Mercury released into the environment from these and other human activities continues to move in the global mercury cycle.

California’s mercury air emissions totaled over 13.7 short tons in 2000. Some of the notable sources were windblown dust, geothermal energy production, cement manufacturing, petroleum-related manufacturing, electric utilities, waste burning, and fluorescent tube breakage.

Publicly owned treatment works (POTWs) are current sources of small, but quantifiable mercury discharges to the State’s waters. By far, the largest contributor of mercury to the State’s waters is the legacy waste from past mining activities. Thousands of tons of mercury were lost to the State’s environment from past placer gold mining. Drainage from more than 300 abandoned mercury mines and prospects found along the California Coast Range continues to release mercury to the region’s waters.

Land disposal of mercury-containing wastes contributes to California’s environmental mercury loading through direct land contamination, surface runoff, leaching to water, and, potentially, atmospheric emissions in landfill gas. A recent study of a Florida municipal landfill showed detectable amounts of mercury compounds in landfill gas, suggesting that landfill gas may be a larger source of mercury air emissions than was previously believed.

Mercury-containing wastes currently disposed in municipal landfills include fluorescent lamps, soils, industrial wastes, ashes, POTW sludges, and non-metallic components from shredded automobiles that are contaminated with mercury.

Section 4, discusses various mercury-containing products, their uses, and some mercury-free alternatives to these products. Mercury’s physical properties, including its high density and liquid state at room temperature make it useful in mechanical switching devices, such as thermostats. Mercury is also used in thermometers, a variety of measurement devices, electrical devices, dentistry, medicine, lighting, and biocides. Despite the decrease in mercury consumption in most applications, releases to the environment are expected to continue as spent mercury-containing products are disposed. A growing list of viable alternatives to mercury-containing products is becoming available for most consumer applications.

Section 5 discusses the contribution of the disposal of waste to environmental mercury loading. Human activities have caused an estimated three-fold increase in the global environment mercury burden. However, in recent years, the use of mercury has been significantly curtailed. U.S. mine production and imports of mercury decreased rapidly between 1986 to 1992; by 1993, most of mercury in the market originated from secondary (recycled) sources. Domestic mercury consumption dropped from more than 2426 short tons in 1976 to less than 441 short tons in 1998.

A number of waste management activities, including waste combustion, are sources of mercury emissions to air. In 1994 and 1995, approximately 87 percent of the nation’s atmospheric mercury emissions originated from combustion point sources. These sources included fossil fuel combustion, which emitted 84 short tons of mercury to the nation’s air in 1996, and waste combustion and incineration, which contributed 60 short tons. California's mercury air emissions from waste management activities, including combustion and landfill sources, were 1.51 tons in 2000, with an estimated 450 pounds, or 15 percent, attributed to broken fluorescent tubes.

A large proportion of California's aquatic mercury load originates from legacy waste from inoperative mercury and gold mines. Other waste sources include leaching and runoff from landfills, atmospheric deposition, and the sewer system. It is estimated that 1180 pounds of mercury from dental offices is present in water entering the State's POTWs for treatment. POTWs typically remove 90 percent of the mercury from their influents. At this rate, 118 pounds of the dental mercury would be discharged to California's waters. The San Francisco Bay Regional Water Quality Control Board has estimated that, annually, between 22 and 286 pounds of mercury from fluorescent lights potentially enters the San Francisco Bay alone.

The USGS estimated that the amount of mercury disposed in landfills fell from 832 short tons in 1990 to 325 short tons in 1996. Mercury from household batteries and lighting comprise of the majority of the discards in the municipal solid waste stream from 1970 to 1989 and was projected to be the same in 2000. U.S. EPA's study showed that the mercury contribution from fever thermometers and thermostats did not show signs of decreasing between 1970 and 1989, and no significant reductions were projected for 2000.

The mercury content of fluorescent lamps decreased sharply between 1985 and 1995, but the rate of reduction has decreased in recent years. Without affecting their life, further reductions in the mercury content of lamps may be increasingly difficult for the industry to achieve. U.S. EPA estimates that 26.7 tons of mercury was disposed in electric lights, nationally, in 1989, while California estimates that 1.3 short tons of mercury from fluorescent lamps will be disposed in 2001. California dentists generated an estimated 2.2 tons of mercury from dental amalgam that was disposed or recycled in 2000. Automobiles potentially contribute 0.75 to 1.5 short tons of mercury to nonhazardous waste landfills per year through auto shredder waste. DTSC's Auto Shredder Initiative sampling and laboratory analyses showed that in 2001, approximately 0.93 tons of mercury was found auto shredder waste (resulting from shredding automobiles and appliances), and that 0.4 short tons originated from automobiles.

Anthropologic mercury air emissions are decreasing as a result of decreases in industrial uses of the metal, as well as improvements in air pollution control devices. While the use of mercury has continued to drop, the environmental mercury load remains unacceptably high. This is evidenced by numerous sport fish consumption advisories, by the existence of mercury-contaminated sites, and by the numerous legislative and regulatory efforts to reduce mercury contamination.

The Department of Toxic Substances Control (DTSC) may recommend regulation of all mercury-containing waste as hazardous waste, in order to promote pollution prevention and recycling and to limit further environmental mercury loading.

Several options for reducing the amount of mercury released to the environment are outlined in Section 6. The promotion of pollution prevention, the use of mercury alternatives, and mercury recycling may be best accomplished by redefining the hazardous waste identification criteria for mercury. DTSC is considering "listing" all mercury-containing waste, regardless of source, as hazardous waste. Where appropriate, certain mercury-containing wastes could be managed under DTSC's universal waste management standards. Disposal of mercury-containing waste would be limited to Class I landfills. In order to facilitate compliance, development and identification of substitutes for mercury-containing products, and development of infrastructure, the implementation of the new mercury criteria would be phased in over time.

Other hazardous waste identification options that may be considered are variations of "listing" mercury-containing waste and are as follows:

- Regulate all waste with intentionally added mercury as hazardous waste
- Regulate all mercury-containing consumer products when they are discarded as hazardous waste
- Develop a new hazardous waste regulatory threshold number
- Status quo

Hazardous waste management options may also be considered include the following:

- Universal waste management
- Full hazardous waste management standards
- Phased implementation
- Landfill disposal - Class I landfill
- Landfill disposal – Class I, II, or III

Additional data is needed in order to fully consider the impacts of the hazardous waste identification and management options listed above. DTSC us requesting this information and data through public workshops that will be held.

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Section 1: Nature and Extent of California's Mercury Contamination: A Summary

I. Introduction

Mercury is a toxic heavy metal that has been used for millennia because of its unique combination of chemical and physical properties. Mercury's widespread use and subsequent release into the environment, combined with its high toxicity, persistence in the environment, and propensity to bioaccumulate and biomagnify in the aquatic food web, make it a contaminant of special concern. Although the use of mercury has been curtailed nationwide, and regulatory standards have been established to limit its release to the environment, mercury continues to cause public health and environmental concerns. These are evidenced by fish advisories issued by California's Office of Environmental Health Hazard Assessment (OEHHA) for a number of California recreational waters.

This section provides an overview of the properties and uses of mercury, the environmental behavior and toxicity of different forms of the metal, and the origin and extent of the State's land, air, and water contamination. The report discusses the disposal of mercury-containing waste not currently regulated under the State's hazardous waste laws. It then focuses on State and federal regulatory standards for mercury in the various environmental media and in the workplace and instances when these standards have been exceeded.

A. Properties of Mercury

Elemental mercury is a liquid over a wide range of temperatures. It exists in a variety of chemical forms in the environment, each of which has distinct chemical and physical properties and toxicology. As it moves through different environmental media, mercury's chemical oxidation state can change. "Through natural chemical and biological reactions, mercury changes form among these species, becoming alternately more or less soluble in water, more or less toxic, and more or less biologically available."[1] Important forms of mercury in the environment include:

- Elemental or metallic mercury, also known as quicksilver (Hg^0),
- Inorganic (oxidized) mercury, including the ore cinnabar (HgS), and
- Organic mercury, including methyl mercury (CH_3Hg).

B. Mercury Uses

Elemental mercury is a liquid at room temperature, expands at a uniform rate with increasing temperature, is relatively dense, and has a low surface tension. These properties have made it very useful in measurement devices such as thermometers, manometers, and barometers. Because it conducts electricity, mercury is also used in a variety of electrical applications, such as electrical lights and switches. Mercury easily forms alloys, called amalgams, with many metals. This property has been exploited in several industries, notably dentistry, gold mining, and chemical manufacturing. Mercury has also been used as a fungicide, mildewicide and pesticide.

C. Health Effects and Public Health

1. Health Effects

Mercury is toxic in all its forms, but its routes of entry, mode of action, and potency are different for each of them. Mercury's toxicology is discussed in detail in Section 2 of this report, but the salient points are briefly summarized here.

Metallic mercury is poorly absorbed in the digestive tract, but readily enters the body via inhalation.[2] The toxic effects of metallic mercury on the central nervous system were known by the 19th century in occupational exposures. Mercury was extensively used in the production of felt, and persons who worked with felt were noted to behave strangely. The Mad Hatter in Lewis Carroll's 1865 novel Alice's Adventures in Wonderland exhibited symptoms of acute metallic mercury poisoning: excitability, delirium, and hallucinations.[3] Metallic mercury toxicity is also characterized by tremors, blurred vision, speech problems, and excessive shyness. Mercury is also toxic to the gastrointestinal tract and the respiratory system.[4]

Inorganic mercury salts are relatively well absorbed in the digestive tract. After ingestion, inorganic mercury is distributed throughout the body in the bloodstream, but it concentrates in the kidneys.[5] Inorganic mercury is toxic to the kidneys. In laboratory animal studies, ingestion of inorganic mercury led to increases in kidney weight and necrosis (death) of the proximal tubules.[6]

Organomercurics, of which methylmercury and dimethylmercury are two, are the most toxic mercury compounds. A Dartmouth University researcher died in 1997 after dermal exposure to a drop of dimethylmercury that passed through her glove.[7] Methylmercury's extreme toxicity has been well documented in a number of epidemiological studies.

2. Public Health

The most infamous outbreak of mercury poisoning was first identified in 1956, among residents of the Minamata Bay region on the island of Kyushu, Japan. These people were highly exposed to methlymercury from ongoing, heavy consumption of fish, which were contaminated with mercury from industrial pollution. According to one author, 59 percent of 628 exposed persons exhibited mental or neurological disorders.[8] Symptoms included tingling in the fingers and toes, difficulty grasping, walking, running, swallowing, and speaking and impaired vision and hearing. "Examination of the brains of severely affected patients that died revealed marked atrophy of the brain (55% normal volume and weight) . . . ."[9] Children born to exposed mothers had a high rate of birth defects, which included mental impairment, delayed development, and severe brain damage.

D. Environmental Issues

1. Bioaccumulation and Biomagnification

Metallic mercury (Hg^0) is converted to the extremely toxic and readily absorbed compound methylmercury by sulfur-reducing bacteria in the lower sediment layers of lakes, rivers, and streams. Unlike metallic mercury, methylmercury is readily absorbed and retained by organisms. This property results in an increase, over time, in the concentration of the methylmercury in aquatic organisms that live in contaminated waters--a phenomenon known as bioaccumulation. Fish take up methylmercury directly, across their gills[10], and predatory fish and birds absorb much of the methylmercury that their prey have absorbed. Consequently, the predators at the highest levels of the food web have the highest concentrations of methylmercury in their bodies. Contaminants that become more concentrated as they move from organisms at lower trophic levels of the aquatic food web (prey) to organisms at higher levels (predators) are said to undergo biomagnification.

2. Persistence

Heavy metals like mercury are believed to originate in supernovae[11], and can neither be created nor destroyed. The mercury that has been used by humans over more than two millennia was extracted mainly from deposits of cinnabar, the most common mercury ore. Mercury is also naturally present in coal, and is released to the environment when coal is burned.

Some of the mercury present in mineral deposits is gradually mobilized to air and water, but human activities to extract and use these resources have significantly increased the amount of mercury that is mobile in the environment.[12] One study estimates that since the beginning of the industrialized period, mercury emissions resulting from human activities have led to threefold increases in worldwide atmospheric and oceanic mercury concentrations.[13] Once mercury is mobilized in the biosphere, it remains there and increases the exposures to humans and the environment.

3. Mobility

Due to its chemical and physical properties, mercury is mobile in the biosphere, both within and between environmental media (land, water, and air).[14] The movement of mercury in the environment is greatly affected by its oxidation state and is described in terms of a global cycle, which will be discussed later in some detail in Section 3. Briefly, the mercury cycle describes the movement of mercury between land, air and water. Mercury is emitted directly to air by both natural and human activities. Some fraction of the airborne mercury is deposited to land or water near the source of emission, while the rest enters the global atmospheric cycle, and is transported worldwide.[15] Once in the atmosphere, mercury can be deposited far from the emission source by two mechanisms: dry deposition and wet deposition (deposition in rain or snow).[16] Atmospheric deposition can be either to land or to water. Mercury is also released directly to water and land by natural and human activities, and can migrate from water to air, and from land to air and/or water.[17]

II. Land Burden

Environmental mercury moves between soil, water, and air and originates from both natural and anthropogenic sources. While the metallic and inorganic forms of mercury most commonly found in soils are toxic in their own right, the especially toxic form methylmercury is found mainly in aquatic environments. The metallic and inorganic forms found in soils contribute to aquatic methylmercury loading, because they can migrate into surface waters, where they are readily converted to methylmercury by aquatic bacteria. Soil mercury levels have increased as a result of human activities. Consequently, the amount of mercury that is mobile in the environment has also risen, as have the risks to public health and the environment.

In order to prevent further increases in soil mercury loading, standards restricting the land disposal of mercury-containing waste have been established in regulations. Some of these standards are in the form of thresholds. Regulatory thresholds are calculated based on predefined levels of acceptable of risk, using theoretical models of the behavior of the contaminant of concern. The models consider a contaminant's concentration, mobility, and toxicity, among other factors. Whether a mercury-containing waste exceeds the established thresholds for mercury determines where it may be disposed, and how it must be managed prior to disposal.

A. Background Mercury Levels

The earth's crust naturally contains small amounts of mercury. In some areas, soil mercury concentrations are elevated above typical background levels. The sources of such elevations vary, and are both natural and anthropogenic. Normally, soil parent materials' mercury content is quite low, and the soil that is formed from them is generally naturally low in mercury. In areas where mercury-rich minerals are abundant, higher soil mercury concentrations are observed. Andersson analyzed data for the mercury content of common soil-forming minerals from numerous published studies and found that igneous rock, coarser-grained soil fractions, sandstone, and limestone all typically have mercury concentrations below 50 nanograms per gram.[18] Andersson states that "(a) normal range of 10-50 ng/g seems to be reasonable for soil parent material, but much higher levels may be found in certain areas."[19] In its *Mercury Study Report to Congress* (U.S. EPA 1997 Study), the United States Environmental Protection Agency cites an estimate that typically, United States soils contain between 8 and 117 ng/g (dry weight) of mercury.[20]

B. Mercury-Containing Waste

1. Hazardous Waste Criteria

Given that there is a range of background mercury levels in soil, regulations were adopted in the mid-1980s to control the disposal of mercury-containing industrial and consumer wastes in landfills. Both State and federal regulations contain criteria to determine whether a waste is hazardous, in order to determine its proper management and disposal. These criteria include threshold concentrations for leachable mercury; wastes that exceed the thresholds are considered hazardous and must be managed accordingly. Both the federal Toxicity Characteristic Leaching Procedure (TCLP) and

California’s Waste Extraction Test (WET) are based on the principle that toxic substances such as mercury can dissolve in landfill leachate. Once dissolved, they can migrate from a disposal area and pollute ground or surface waters. While both procedures are designed to simulate the leaching of chemicals that are buried in a landfill, they differ in some respects, and the WET is generally considered more aggressive for inorganic chemicals. In both federal and State leaching procedures, mercury-containing waste is classified as hazardous when it has an extractable mercury concentration at or above 0.2 mg/L.

In California, wastes whose leachable mercury concentrations do not exceed the 0.2 mg/L threshold are nevertheless classified as hazardous if their total mercury concentration equals or exceeds 20 mg/kg. Such “Total Threshold Limit Concentrations” (TTLC) have no counterparts in the federal waste classification scheme.

Whether or not their mercury concentrations exceed State and federal thresholds, certain “listed” wastes are classified as hazardous. U.S. EPA has established four hazardous waste lists in its regulations. Several listed wastes are included because they contain mercury.

The hazardous waste identification criteria determine what handling and disposal requirements apply to a waste. Mercury-containing waste that meets any of the criteria must be stored, transported, and disposed in a manner that is protective of public health and environment, in accordance with hazardous waste management standards found in federal and State regulations.

2. Disposal Options for Mercury-Containing Waste

Disposal options are limited for mercury-containing waste that meets hazardous waste identification criteria. In California, hazardous waste may only be disposed to land in Class I landfills, which are hazardous waste landfills. Class I landfills must meet stringent requirements to prevent migration of chemicals into the environment. They must be constructed with a protective liner, leachate collection system, and are subject to site-specific permitting requirements and waste acceptance criteria. The management of a Class I landfill is overseen by two state agencies: the Regional Water Quality Control Board (RWQCB) in whose jurisdiction it is located, and the Department of Toxic Substances Control (DTSC).*

A second category of landfills, Class II landfills, are designed to accept designated wastes—wastes whose land disposal may threaten water quality. Some Class II landfills accept municipal solid waste, but others are restricted from doing so. Typically, Class II landfills accept only lower risk hazardous waste. Before it may accept any hazardous waste, a Class II landfill must obtain a variance from DTSC, and must obtain a permit from the local RWQCB and the California Integrated Waste Management Board (CIWMB). *

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* Local Air Pollution Control Districts (APCDs) and Air Quality Management Districts (AQMDs) oversee air quality issues at landfills.

Class III landfills, also referred to as municipal solid waste landfills, are also overseen by RWQCB and CIWMB.* Because the design, siting, and permitting requirements for Class III landfills are less stringent than those for Class I and II landfills, hazardous substances are more likely to leach into the surrounding environment from Class III landfills. For this reason, they may generally accept only non-hazardous waste for disposal. In special instances, upon approval of DTSC, the local RWQCB, and CIWMB, Class III landfills may accept lower risk hazardous wastes, such as asbestos, treated wood and wastes containing solid metal.

If landfill gas controls are required by the air pollution control agencies, Class II and III landfills are designed to include landfill gas collection systems to either allow the landfill gas collected to be burned for energy recovery or flared. Class I landfills do not have landfill gas collection systems as they do not accept putrescible or volatile organic waste, which creates an environment to produce landfill gas.

C. Landfill Deposition of Mercury

1. Annual Disposal of Non-Hazardous Mercury-Containing Waste—Two Estimates

Mercury-containing waste that meets hazardous waste identification criteria is subject to more stringent management and disposal standards than is mercury-containing waste that does not meet the criteria. Disposal of nonhazardous waste that contains mercury in Class III landfills is a concern, due both to the less protective management standards for the waste prior to disposal, and the less stringent design and operation standards for the landfills.

a. United States Geological Survey (USGS) Estimate

In its study, *The Materials Flow of Mercury in the Economies of the United States and the World* (USGS 2000 Study), the USGS estimates the total amount of mercury deposited in U.S. municipal landfills. The estimates are based on data from 1994 and 1995, published in the U.S. EPA 1997 Study[21]. USGS calculates the following values for nationwide landfill disposal of mercury:

- The total mass of mercury in municipal solid waste in the United States was 340 tons†.
- 299 tons of mercury were contained in waste that was directly disposed in municipal landfills.
- The remaining 41 tons of municipal waste were incinerated in municipal waste combustors.
- The average mercury-removal efficiency of various emission control devices[22] used for municipal waste incinerators was determined to be 27 percent. This value was used to calculate that approximately 11 tons of mercury were captured by these devices and subsequently deposited in landfills, while the remaining 30 tons were emitted to the atmosphere.

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† All references to 'tons' denote short tons. For consistency, all weight measurements were converted to short tons in this report. A short ton is 2000 pounds, or 0.907 metric tons. A metric ton is 1000 kilograms, or 2200 lbs.

- The total amount of mercury going to landfills was calculated to be 310 tons. (340 tons – 41 tons + 11 tons = 310 tons.)

According to United States Census data, California's population represents approximately 12 percent of the total United States population.‡[23] Assuming the per capita generation of municipal solid waste is approximately the same in California as in the United States, and using USGS's estimate of 310 tons of mercury disposed in landfills nationally, approximately 37.2 tons of mercury were disposed in the California's landfills in each of 1994 and 1995.

b. U.S. EPA Estimate
In the U.S. EPA 1997 Study, U.S. EPA estimates that 227.6 tons of mercury were discarded in the United States in 1995, and that 144.6 tons would be discarded in 2000. This data was taken from a 1992 U.S. EPA study *Characterization of Products Containing Mercury in Municipal Solid Waste in the United States, 1970 to 2000 (*U.S. EPA 1992 Study). The 1992 data was modified to account for federal legislation adopted in 1996 that restricted the use of mercury in batteries, which led to the elimination of mercury from most batteries.[24] The contribution of mercury in discarded fluorescent tubes to the total was also adjusted downward in the 1997 study to account for the reduction in the average amount of mercury used in their manufacture.[25] However, the 1997 study did not anticipate U.S. EPA's 1999 rulemaking that added mercury-containing hazardous waste lamps to the universal waste program, nor the inclusion of these lamps in universal waste regulations promulgated in many states, including California. Consequently, the U.S. EPA 1997 Study may overestimate the amount of mercury disposed into municipal solid waste landfills.

The amount of mercury disposed by Californians can be calculated from U.S. EPA's national data, and can be compared with the value calculated from USGS's estimate. Assuming, as before, that Californians accounted for 12 percent of total U.S. disposal, approximately 27.3 tons of mercury were disposed in the State's municipal landfills in 1995, and 17.3 tons would have been disposed in 2000.[26]

The estimate based on the U.S. EPA 1997 Study is somewhat lower than the estimate based on the USGS 2000 Study. This difference may be explained by the fact that U.S. EPA's national estimate is based on the disposal of a list of mercury-containing products, while USGS's total is based on estimates of the loss of mercury from municipal waste combustors, some of which may originate from wastes not included in

‡ According to the Census Bureau, in 1990, California had 29.76 million of the 248.7 million people in the United States. In 2000, the State's population was 33.87 million of the 281.4 million people in the nation. California's percentage of the nation's population has remained constant, at approximately 12 percent.

U.S. EPA's list. Nevertheless, the two values are in rough agreement.

California adopted its Universal Waste Rule in 2000, which provided alternative management requirements for mercury-containing lamps and thermostats in order to encourage their proper management and diversion from non-hazardous waste landfills. Any decrease in the disposal of these items that may have resulted from these recently adopted regulations is not reflected in either estimate.

2. Leaching of Mercury from Landfills

Groundwater at municipal solid waste (Class III) landfills is currently monitored for mercury under the waste discharge requirements issued by the RWQCBs. If the concentration of any constituent of concern exceeds the corresponding Maximum Contaminant Level (MCL), enforcement is brought by the local RWQCB. The MCL for mercury is MCL 0.002 mg/L.

When U.S. EPA published its proposed rule on spent mercury lamps in 1994, the agency requested data on the mercury content of landfill leachates or groundwater. Groundwater modeling and field data submitted in response to this request, along with U.S. EPA's own data, showed that mercury can migrate from municipal landfills to contaminate drinking water supplies. " . . . [Actual] site data from recent and on-going studies support the Agency's conclusion that mercury is present in significant concentrations in both leachate and groundwater at non-hazardous waste landfill sites, including municipal solid waste landfills, and has migrated off-site to drinking water sources (in some instances in concentrations exceeding Federal drinking water standards)."[27] Data compiled by DTSC corroborates U.S. EPA's findings; landfill leachate samples analyzed in four separate studies contained detectable mercury, sometimes in excess of federal primary drinking water standards.[28]

In a review of data from California landfills in the Waste Management Unit Database System (WMUDS), mercury concentrations exceeded the MCL in three of 13 wells analyzed. The maximum concentrations were 0.004 mg/L in water sampled at the Tri-cities and Victorville landfills. One of five leachate samples analyzed contained mercury in excess of the MCL: a sample from the Zanker Road Landfill, which contained 0.0032 mg/L mercury.[29]

In addition to concerns about the leaching of elemental and inorganic mercury from landfills, a recent study shows that methylmercury can be formed by bacteria in landfills, and can be directly emitted to air. Lindberg, *et al.*, report that various mercury species were detected in landfill gas from a Florida municipal landfill.[30] Total gaseous mercury was detected at concentrations in the $\mu g/m^3$ range, dimethylmercury was found in the ng/m^3 range, and methylmercury was detected in landfill gas condensate. The total gaseous mercury concentrations detected were "comparable to Hg levels in flue gas and the immediate downwind plume of coal-fired power plants . . .."[31] The authors suggest that direct landfill emissions to air may account for methylmercury that has been detected in continental rainfall.

D. Mercury Contaminated Sites in California

1. CalSites Data

Since the mid-1980s, generators of mercury-containing waste have been subject to hazardous waste determination requirements. As discussed earlier, mercury-containing waste that meets hazardous waste identification criteria must be managed in accordance with storage, treatment, transportation, and disposal requirements designed to protect public health and environment. In spite of this extensive hazardous waste regulatory scheme, past and current human activities have led to unacceptable land contamination with mercury in some locations. Mercury-contaminated sites require assessment of the risks they pose to the public and the environment through all potential exposure routes. When a site's level of mercury contamination is found pose significant risk, mitigation or cleanup is required.

DTSC's Site Mitigation Program maintains an automated database, which contains information on properties in California where hazardous substances have been released, or where the potential for a release exists. This database, referred to as "CalSites," is used primarily by DTSC staff as an informational tool to evaluate and track activities at properties that may have been affected by the release of hazardous substances. In April 2001, a search was completed for those sites where mercury was identified in CalSites as a known or suspected hazardous waste/substance. Eighty-one sites were identified in this search, ten of the eighty-one sites show DTSC actively working to remediate either in a lead role or in a support capacity.

It should be noted that the CalSites database should not be considered to be the sole database for identifying sites in California that contain mercury contamination.

2. Tailings Dumps

Past mining of cinnabar in California's Coast Range created mine-tailing dumps. These dumps contain significant amounts of exposed residual mercury. Tailings dumps contribute to environmental mercury loading two ways: they directly contaminate the land, and their mercury can leach and migrate, contributing to California's water mercury burden. The efficiency of "mercury recovery during retorting ranges from 90 to 95 percent, which results in calcine [tailings] that may contain from 5 to 10 percent of the mercury originally present in the ore."[32] Sulfur in the piles of tailings reacts with oxygen and rainwater to form sulfuric acid, which readily dissolves mercury in the ore and carries it into creeks.[33] One study found that more than 80 percent of the dissolved mercury in Marsh Creek -- a small coast range creek -- could be traced to a single pile of exposed tailings at an abandoned mercury mine site.[34]

III. Mercury in California's Air

Mercury and mercury compounds (mercury) found in California's air are the result of emissions from both natural and anthropogenic sources. The California Air Resources Board (ARB) is the state agency that maintains the emissions inventory for mercury in the air. It should be noted that emissions of mercury into the air are transitory and are eventually deposited onto either land or water where they contribute to the mercury concentrations found in those environmental media.

Natural sources of mercury air emissions include volcanoes, wild fires, degassing from the earth's crust, and evaporation from the world's oceans.§[35] Anthropogenic mercury emissions originate from a number of sources, including point and area-wide sources. Point sources emitting mercury include electric generation facilities, refineries, and cement manufacturers. The primary area-wide sources of mercury emissions are windblown dust and waste burning. Other anthropogenic sources of airborne mercury include the breakage of mercury-containing lamps and laboratories (research and analytical).

A. Ambient Air Concentrations of Mercury in California

California's median air mercury concentration is below the Limit of Detection of 3.0 ng/m^3. Ambient air mercury concentration data for the past ten years can be accessed at the following ARB web site:
www.arb.ca.gov/aqd/toxics/statepages/hgstate.html

The median ambient air concentrations reported at this web site do not reflect elevated air concentrations that may occur near stationary sources of mercury emissions.

B. California Air Toxics Programs

California's air toxics programs began in the late 1980's. Mercury has been a substance of interest to these programs since their inception. The most significant of these programs include the Toxics Air Contaminant Program, the Air Toxics "Hot Spots" Program, and the Children's Environmental Health Protection Program. We will discuss each of these programs and how mercury is included in each of them.

1. The Toxics Air Contaminant Program (AB 1807)

The ARB and OEHHA have identified mercury as a Toxic Air Contaminant (TAC). The process for identification of TACs was initiated by Assembly Bill 1807 (AB 1807, Tanner, 1983), also known as the "Toxic Air Contaminant Identification and Control Act." The bill requires the ARB and OEHHA to use criteria relating to "the risk of harm to public health, amount or potential amount of emissions, manner of, and exposure to, usage of the substance in California, persistence in the atmosphere, and ambient concentrations in the community" in the prioritization for the identification and control of air toxics. If a substance is identified as a TAC, the ARB staff " . . . reviews the emission sources of an identified TAC to determine if any regulatory action is necessary to reduce the risk."[36] The information generated by the TAC process that resulted in mercury (and mercury compounds) being designated as a TAC can be found at the following ARB web site:
www.arb.ca.gov/toxics/tac/toctbl

§ Note: a significant amount of the mercury emitted to the atmosphere from the earth's oceans and crust is re-emitted anthropogenic mercury that was previously deposited.

2. The Air Toxics “Hot Spots” Program (AB 2588)

With mercury’s designation as a TAC, it is a substance for which facility operators must estimate and report emissions as required by the Air Toxics "Hot Spots" Information and Assessment Act (AB 2588, Connelly, 1987). AB 2588 requires stationary sources to report the routine emissions of a list of substances. The Air Toxics “Hot Spots” Program’s (the Program) primary goals have been to collect data on the emissions of toxic substances, to identify facilities whose toxic emissions have localized effects, to determine the health risks posed by these emissions, and to notify local residents of these risks. The program was further refined by Senate Bill 1731 (SB 1731, Calderon, 1992) which amended the "Hot Spots" Act to require operators of facilities whose emissions pose significant risks to reduce these risks until they are no longer significant.[37]

Facility operators have been reporting Air Toxics “Hot Spots” emission inventory data to the ARB since 1989. Not all facilities statewide are subject to the Program. The ARB works closely with the local air pollution control districts and air quality management districts (the districts) to ensure that facilities that could potentially pose a risk to the quality of life of the local residents are required to submit emission inventories and to evaluate these potential risks. The mercury emissions estimates collected to meet the requirements of the Air Toxics “Hot Spots” Program serve as the ARB’s statewide point source data for mercury air emissions.

3. The Children’s Environmental Health Protection Program (SB 25)

Children can sometimes be more at risk than adults from the harmful health effects of air pollution. To provide further protection to children, the ARB is implementing a number of activities to evaluate and reduce those health risks. Senate Bill 25 (Escutia, 1999) established specific requirements to examine the impacts of air pollution on children’s health. The ARB’s efforts include:

- Review of ambient air quality standards to determine whether the standards adequately protect the health of the public including children,
- Revision of those standards found to be inadequate,
- Expansion of monitoring for air pollutants to assess the monitoring network’s ability to measure children’s exposure to air pollution, and
- Identification and control of TACs to which children may be especially sensitive (the most significant of those TACs will be determined by OEHHA).

Mercury is one of the substances that is being monitored in the Children’s Environmental Health Protection Program. The scientific review panel working with OEHHA to prioritize the most significant substances has placed mercury in the second tier of concern. This decision was based on several factors including mercury’s relatively high neurological and developmental toxicity, but its low ambient levels in California. Additional information about the Children’s Environmental Health Protection Program can be obtained by visiting the following web site:
www.arb.ca.gov/ch/ceh/ceh.htm

C. Mercury Health Data Associated with Air Exposures

As part of the process of evaluating risks under the Air Toxics "Hot Spots" Program, ARB and OEHHA have approved Reference Exposure Levels (RELs) for some of the TACs, for use in health risk assessments. RELs have been developed for inorganic mercury and compounds, and for organic mercury and compounds. OEHHA defines an REL as the " . . . concentration level at or below which no adverse health effects are anticipated for a specified exposure duration . . ..."[38] The approved REL values for mercury and mercury compounds for chronic inhalation, chronic oral, and acute inhalation are summarized in Table 1-1.

Table 1-1: OEHHA/ARB Approved Risk Assessment Health Values[39]

NON-CANCER EFFECT (UNITS)	MERCURY AND COMPOUNDS (INORGANIC)	MERCURIC CHLORIDE	MERCURY AND COMPOUNDS (ORGANIC)**
Acute Inhalation ($\mu g/m^3$)	1.8	1.8	NA††
Chronic Inhalation ($\mu g/m^3$)	0.09	0.09	1.0
Chronic Oral (mg/kg/day)	0.0003	0.0003	NA††

D. Occupational Exposure Standards

It is relevant to note when discussing air standards and acceptable inhalations risks that a variety of industrial hygiene standards have been established for several different forms of mercury to protect occupationally exposed workers from mercury's toxic effects. Some of these standards are enforceable, while others are advisory in nature. Table 1-2 summarizes some of the existing standards metallic, inorganic, and organic mercury.

** Values also apply to methylmercury

†† NA = None adopted

Table 1-2: Industrial Hygiene Limits for Occupational Exposure (mg/m^3) Mercury Inhalation

MERCURY FORM	CAL - OSHA PEL[‡‡]			ACGIH TLV[§§]			NIOSH[***] REL/IDLH			
	PEL[†††]	STEL[‡‡‡]	C[§§§]	TLV[****]	STEL	C	REL[††††]	STEL	C	IDLH[‡‡‡‡]
Mercury Vapor	0.05	_ _	0.1	0.025	—	—	0.05	—	—	10
Alkyl Mercury (organo)	0.01	0.03	0.04	0.01	0.03	—	0.01	0.03	—	2
Aryl and inorganic Compounds	—	—	0.1	0.1	—	—	N/A	N/A	N/A	N/A

It should be noted that the industrial hygiene occupational exposure levels to all forms of mercury are significantly higher than the RELs established by OEHHA. For example, the federal Occupational Safety and Health Administration's (OSHA's) PEL for mercury vapor of 0.05 mg/m^3 or 50 $\mu g/m^3$, is approximately 500 times higher than the REL for chronic inhalation, which is 0.09 $\mu g/m^3$. These differences may be attributable to differences in the risk assessment methodology and default assumptions that were used to derive the respective values.

E. Air Emissions

The ARB stores statewide air emissions data in the California Emission Inventory Development and Reporting System (CEIDARS). CEIDARS contains emissions information for criteria pollutants (oxides of nitrogen, total organic gases, particulate matter, etc.) and for toxic substances. These data are gathered for stationary, area-wide, on-road mobile, off-road mobile, and natural sources. Inventories of emissions to air are revised on an annual basis to reflect the addition or deletion of sources, revised emission estimation methodologies, and revised speciation profiles. The emission estimates of mercury cited in this report are associated with the emission inventory for

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‡‡ **Cal-OSHA** – California Occupational Safety and Health Administration.
§§ **ACGIH -** American Conference of Governmental and Industrial Hygienists.
*** **NIOSH -** National Institute of Occupational Safety and Health. Mercury vapor includes both aryl and inorganic mercury.
††† **PEL** - Permissible Exposure Limit. The maximum permitted 8-hour time-weighted average concentration of an airborne contaminant.
‡‡‡ **STEL** - Short-term exposure limit. A 15-min time-weighted-average exposure that should not be exceeded at any time during a workday even if the 8-hour time-weighted-average is within the threshold limit value.
§§§ **C** – Ceiling. These values should not be exceeded at any time.
**** **TLV** – Threshold Limit Value. The time-weighted average concentration for a conventional 8-hour workday and a 40-hour workweek, to which it is believed that nearly all workers may be repeatedly exposed, day after day, with our adverse effect.
†††† **REL** – Recommended Exposure Levels. These are time-weighted averages (TWA) concentrations for up to a 10-hour workday during a 40-hour workweek.
‡‡‡‡ **IDLH** - Immediately Dangerous to Life or Health. The maximum environmental concentration of a contaminant from which one could escape within 30 min without any escape-impairing symptoms or irreversible health effects.

the 1996 calendar year.

The stationary sources in CEIDARS are categorized as point sources and aggregated point sources. Generally speaking, a point source is a facility that emits greater than ten tons per year of one or more of the criteria pollutants. The aggregated point sources are those smaller facilities that have significantly similar emissions and a relatively small number of processes associated with them. Gasoline service stations and dry cleaners are examples of aggregated point sources. Emissions estimates for the vast majority of these facilities are developed by the facility operator under the auspices of the Air Toxics "Hot Spots" Program, but there are cases where the districts will develop the emission estimates for the facility operators. The mercury compounds facility operators are required to estimate and report include mercury, mercuric chloride, and methyl mercury.

Area-wide sources are estimated by the ARB and include the very small individual sources (residential combustion sources are an example) and the widely distributed sources that cannot be tied to a single location (consumer products, for example). Emission estimates of toxic substances, such as mercury, are developed by speciating criteria pollutant emissions associated with these sources.

Emissions from on-road and off-road mobile sources are estimated using California-specific models developed by the ARB. The sources included in the on-road model include cars, trucks, and buses. The sources included in the off-road model include aircraft, recreational equipment, and agricultural equipment. Emissions of toxic substances from mobile sources are developed by speciating criteria pollutant emissions associated with these sources.

Sources of emissions from natural sources include biogenics and wild fires. Emissions of toxic substances from natural sources are developed by speciating criteria pollutant emissions associated with these sources.

Specific mercury emission estimates from each of these source types will be discussed in detail in Sections 3 and 5 of this report.

IV. Water Mercury Burden

A. Background/Ambient Water Quality

Open ocean concentrations of dissolved mercury have been measured between 0.5 ng/l and 3.0 ng/L, while coastal concentrations were measured higher, ranging from 2 to 15 ng/L[40]. Both concentration ranges are well below the recommended ambient water quality criterion of 50 ng/L. However, ambient concentrations in some water bodies exceed this criterion. For example, the San Francisco Bay RWQCB reports preliminary mercury concentrations ranging from 2 to greater than 100 ng/L in the San Francisco Bay[41].

B. Standards

1. Types of Water Quality Goals

There are many water quality criteria and goals that are designed to protect specific beneficial uses of water. These water quality goals can be used to interpret narrative water quality objectives. Table 1-3 summarizes the main water quality goals that are discussed in this document. The Reference section at the end of this report lists the sources of these limits, including Internet addresses, where available.

Table 1-3: Summary of Water Quality Goals in California[42]

Water Quality Goal	**Agency**	**Law**	**Meaning**
Maximum Contaminant Levels (MCLs)	California Department of Health Services (DHS)	California Safe Drinking Water Act.	MCLs are set a level as close as is technically and economically feasible to the public health goal (PHG) (see below), placing primary emphasis on the protection of public health. Carcinogens: often set at or near the level of up to one excess case per million people per 70-year lifetime exposure, but may be less restrictive because of technical and economic feasibility Non-carcinogens: set at level that would pose no adverse health effects
Maximum Contaminant Level Goals (MCL Goals or MCLGs)	U.S. EPA	National Primary Drinking Water Regulations	Carcinogens: zero Non-carcinogens: levels posing no risk of adverse health effects.
Public Health Goals (PHGs)	OEHHA	California Safe Drinking Water Act of 1996	Levels of contaminants in drinking water that would pose no significant health risk to individuals consuming the water on a daily basis over a lifetime.
State Action Levels	DHS		Carcinogens: one excess case per million people for a lifetime exposure Non-carcinogens: a level that would pose no adverse health effects
California Environmental Protection Agency (Cal/EPA) Cancer Potency Factors	OEHHA		Cancer potency factors for inhalation and oral exposures to many chemicals.
Integrated Risk Information System (IRIS)	U.S.EPA Office of Research and Development National Center for Environmental Assessment		Reference doses (RfDs): calculated safe exposure levels with respect to non-cancer health effects. RfDs may be converted into concentrations in drinking water (mg/L or µg/L) using standard exposure assumptions.
Drinking Water Health Advisories and Water Quality Advisories	U.S. EPA		Advisories for short-term (1-day exposure or less or 10-day exposure or less), long-term (7-year exposure or less), and lifetime human exposures through drinking water.

Water Quality Goal	Agency	Law	Meaning
Suggested No-Adverse-Response Levels (SNARLs)	National Academy of Sciences (NAS)		Published in the nine volumes of Drinking Water and Health (1977 to 1989).
Proposition 65 Regulatory Levels	OEHHA	California Safe Drinking Water and Toxic Enforcement Act of 1986	Requires notification prior to exposing persons to listed carcinogens or reproductive toxins, and prohibits discharges to sources of drinking water. Warnings are not required and discharges are not prohibited if: for carcinogens, risks are at one per 100,000 lifetime risk or lower; reproductive toxins, exposures are less than 1/1,000 of the no observable adverse effect level
National Ambient Water Quality Criteria	U.S. EPA	Section 304(a) of the Clean Water Act	Provide guidance to states in adopting water quality standards. Concentrations based on exposure from drinking water and consuming aquatic organisms (fish and shellfish) that live in the water.
California Toxics Rule (CTR) Criteria	U.S. EPA	Federal Clean Water Act	U.S. EPA-promulgated water quality criteria for priority toxic pollutants for California's inland surface waters and enclosed bays and estuaries.

Some of these goals/limits have been established for mercury. These are summarized in Table 1-4, below.

Table 1-4: Summary of State and Federal Water Quality Standards for Mercury§§§§

Units are micrograms per liter (µg/L)

Inorganic Constituent				**INORGANIC MERCURY**	**MERCURIC CHLORIDE**
Drinking Water Standards (Calif. And Federal) MCLs	CA DHS Primary MCL			2	
	U.S. EPA Primary MCL			2	
	U.S. EPA MCL Goal			2	
OEHHA Public Health Goal (PGH) in Drinking Water				1.2	
U.S. EPA IRIS RFD as a Drinking Water Level					0.2
U.S. EPA SNARL for non-cancer Toxicity				2	
California Prop 65 Level as a Drinking Water Level				R*****	R*****
U.S. EPA National Recommended Ambient Water Quality Criteria	Non-cancer Effects—Drinking Water Sources (water and organisms)			0.050	
	Non-cancer Effects—Other Waters (aquatic organism consumption only)			0.051	
	Freshwater Aquatic Life Protection—Recommended Criteria		Continuous concentration (4-day Average)	0.77	
			Maximum Concentration (1-hour Average)	1.4	
California Toxics Rule (U.S. EPA)	Inland Surface Waters	Human Health (30-day average)	Drinking Water Sources (consumption of water and organisms)	0.05	
			Other Waters (aquatic organism consumption only)	0.051	
	Enclosed Bays and Estuaries	Human Health (30-day average) aquatic organism consumption only		0.051	
California Ocean Plan Numerical Water Quality Objectives	Marine Life Aquatic Protection		6-month Median	0.04	
			Daily Maximum	0.16	
			Instantaneous Maximum	0.4	
U.S. EPA National Recommended Ambient Water Quality Criteria—Saltwater Aquatic Life Protection	Recommended Criteria		Continuous Concentration (4-day average)	0.94	
			Maximum Concentration (1-hour average)	1.8	

§§§§ From: California Regional Water Quality Control Board, Central Valley Region: *A Compilation Of Water Quality Goals*

***** Reproductive Toxin

2. Total Maximum Daily Loads (TMDL) for Mercury

The Federal Clean Water Act requires that California identify water bodies that do not meet water quality standards and develop total maximum daily pollutant loads for those water bodies. A TMDL represents the total loading rate of a pollutant that a water body can receive and still meet applicable water quality standards. Once a TMDL for a particular pollutant has been established, the load is allocated to all sources in the watershed, point and non-point, which must implement control measures as needed to reduce their discharges to the levels allocated to them. The San Francisco Bay RWQCB, in its TMDL Report, has proposed a sediment mercury target of 0.20 µg/g, and targets for methylmercury in bay fish that are 50 percent below current levels[43].

C. Water Mercury Sources

Mercury can enter impacted water bodies like the San Francisco Bay estuary from a variety of sources. Because of mercury's tendency to adsorb to particulates, the remobilization of contaminated sediments can be a significant source of mercury loading. The San Francisco Bay RWQCB has identified remobilized sediments from the Central Valley as the largest source of mercury loading in the San Francisco Bay[44]. The next largest mercury input identified by the RWQCB is the remobilization of contaminated sediments within the Bay that are gradually being eroded away.[45] Other important sources are watersheds within the San Francisco Bay Estuary, direct discharge of mercury-containing wastewater, and direct atmospheric deposition.[46] The relative contributions of these sources may differ in other impacted water bodies.

V. Public Health / Environmental Issues

Many regulatory efforts are already underway to reduce environmental mercury loading. They include management requirements for hazardous waste, mandates for the reduction of air emissions from stationary sources, point source controls on wastewater discharges, occupational exposure limits for mercury, and bans on the use of mercury in consumer products. Additionally, efforts are ongoing to mitigate and clean up contaminated sites. These activities are designed to reduce the potential exposure of humans, wildlife and the environment and the risks that such exposures entail.

The risks posed to humans and wildlife from environmental mercury exposure can be estimated through a process known as risk assessment. OSHA and industrial hygiene advisory groups also use a risk assessment process, which is specific to a workplace exposure setting, to determine the occupational exposure limits. Risk assessment involves the evaluation of potential exposure routes to the sensitive receptor (human or wildlife). The concentrations of a substance that can be assimilated by the sensitive receptor through all potential exposure routes are determined, and are compared to a reference dose. (A reference dose is one that is considered acceptable over the receptor's lifetime.) The specific details of the risk assessment process are not within this scope of this report.

A. Methylmercury in Fish / Consumption Advisories

Although regulatory standards limiting releases of mercury into the environment are in place, mercury's ability to move from air and soil into water continues to pose a public health risk. This risk is due to methylmercury's propensity to bioaccumulate in fish and human consumption of methylmercury contaminated sport fish. Using reference doses and complex risk assessment calculations, OEHHA has determined that mercury fish advisories are necessary in California's recreational waters.

Currently, there are OEHHA advisories against the consumption of any fish from the Guadalupe, Caldero, and Almaden Reservoirs, as well as the Guadalupe River and Guadalupe and Alamitos Creeks as a result of mercury contamination originating from nearby abandoned mines.[47] OEHHA has issued several other fish consumption advisories due in part or entirely to mercury contamination.[48] These advisories specify maximum consumption limits for specific fish species and sizes. These are summarized in Table 1-5.

Table 1-5: Sport Fish Consumption Advisories for Mercury Contaminated Water Bodies, 1999

Affected Water Body	Consumption Limits General Population	Fish Species
Clear Lake	Adults: ranges from 1 lb. to 10 lbs. per month, depending on species and size. Children aged 6 to 15: half the maximum amounts recommended for adults, ranging from 0.5 lb. to 5 lbs. per month, depending on species and size. Pregnant/nursing mothers, children under 6: No consumption.	Bass (largemouth and smallmouth), catfish (white and channel), trout (rainbow), brown bullhead, Sacramento blackfish, crappie, hitch
Lake Berryessa	Adults: ranges from 1 lb. to 10 lbs. per month, depending on species and size. Children aged 6 to 15: half the maximum amounts recommended for adults, ranging from 0.5 lb. to 5 lbs. per month, depending on species and size. Pregnant/nursing mothers, children under 6: No consumption.	Bass (largemouth and smallmouth), catfish (white and channel), trout (rainbow)
San Francisco Bay/Delta (interim)	Adults: no more than two 8-oz. meals per month. No striped bass over 35 inches. Pregnant/nursing mothers, children under 6: no more than one 8-oz. meal per month. No striped bass over 27 inches or shark over 24 inches. Everyone: no croakers, gobies, or shellfish from the Richmond Harbor Channel area.	Sport fish, including sturgeon and striped bass from the delta
Lake Hermann	Adults: no more than 1 lb. largemouth bass per month. Children aged 6 to 15: no more than 8 oz. largemouth bass. Pregnant/nursing mothers, children under 6: No consumption.	Largemouth bass Largemouth bass Any fish
Guadalupe Reservoir	No consumption.	Any fish
Calero Reservoir	No consumption.	Any fish
Almaden Reservoir	No consumption.	Any fish
Guadalupe River	No consumption.	Any fish
Guadalupe Creek	No consumption.	Any fish

Affected Water Body	Consumption Limits General Population	Fish Species
Alamitos Creek	No consumption.	Any fish

B. Mercury Contaminated Sites

Mercury-contaminated sites listed in the CalSites database were previously discussed. Mercury may be the only hazardous contaminant present at a contaminated site, or it may be one of many chemicals of concern. After a site is fully characterized, a risk assessment is performed. Typically during the site characterization process, public access to a contaminated site is restricted, in order to reduce any potential exposure of the public to the chemicals of concern. If necessary, cleanup activities or mitigation measures are performed on the contaminated site.

In spite of the fact that these measures are taken to assess and clean up land contamination, unintentional contamination of land with mercury continues to be an issue. Contamination may occur through disposal of non-hazardous mercury-containing waste in Class III landfills, or through illegal garbage dumping in rural areas. Because of the persistence and bioaccumulative properties of mercury, nonhazardous waste that contains mercury may add to the current risk to public health and environment.

C. Nontraditional Sources of Mercury

Some activities that lead to human exposure to mercury occur outside of the workplace, and fall outside of the California OSHA's regulatory authority. These include recreational and hobby activities. Although measures are taken to educate the public of the dangers of mercury, these activities are not formally regulated in California, although they may pose risks to the public. They include recreational gold mining, where recovered gold is often found amalgamated with mercury. Some recreational gold miners refine gold at their homes, exposing themselves to mercury in the process, as well as emitting mercury to the air. Waste liquid mercury collected in the course of recreational gold recovery is either disposed in an environmentally sound manner through household hazardous waste collections, or disposed onto land or in the sewer via the toilet, causing an additional mercury burden to the State's waters.

Section 1 Key Points:

- Mercury is ubiquitous in the environment due to its natural occurrence and its widespread current and historical use.
- Mercury is a contaminant of special concern because of its toxicity, persistence, environmental mobility, and ability to bioaccumulate.
- Mercury's health and environmental hazards have led to the development of numerous regulatory standards for mercury in waste, air, and water.
- Standards for occupational exposure airborne to mercury have also been adopted, due to its health hazards.
- In spite of the existing regulatory standards, California's environment continues to be contaminated with mercury.
- Airborne mercury is a concern because it is eventually deposited on land and water.
- Mercury is contained in waste that is classified as non-hazardous under current regulatory criteria.
- The disposal of non-hazardous products contributes a significant amount of mercury to municipal landfills.
- Mercury can dissolve in landfill leachate and potentially contaminate the State's waters.
- Aquatic mercury is converted to a very toxic and bioaccumulative form, methylmercury, by certain bacteria.
- Mercury land contamination at a number of sites in California has made cleanup or other mitigation activities necessary.
- Some of California's water bodies exceed water quality standards for mercury. The Federal Clean Water Act requires that total maximum daily loads be developed for mercury in these water bodies.
- California's Office of Environmental Health Hazard Assessment has advised the public to restrict or eliminate its consumption of specific sport fish from several water bodies, due to elevated levels of methylmercury in the fish.

Endnotes

[1] Jones, Alan B., and Slotton, Darrell G., 1995. Mercury Effects, Sources, and Control Measures. San Francisco Estuary Institute. p. 3.

[2] Carpi, Anthony, 1998. The Toxicology of Mercury. City College of New York. p. 2.

[3] Carpi, 1998. p. 2.

[4] United States Environmental Protection Agency (EPA), 2001. Mercury and Compounds. Office of Air Quality Planning & Standards. Internet web site, accessed May 23, 2001: http://www.epa.gov/ttn/uatw/hlthef/mercury.html

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Section 2: Mercury's Chemistry and Toxicology--Human and Environmental Hazards

I. Introduction

Mercury's health and environmental hazards stem from its toxicity and its mobility in the environment. As discussed briefly in Section 1, each form of mercury has distinct chemical and physical properties and toxicology. This section provides an overview of the chemistry of the three most environmentally important forms, their role in the global mercury cycle, and their toxicology. These discussions provide context for the concerns about the hazards of mercury in California's environment and the adequacy of the current efforts to control human contributions to the State's mercury problem.

II. Physical and Chemical Properties of Mercury and Mercury Compounds

A. Melting Point, Volatility

Mercury can exist in three oxidation states: Hg^0 (elemental or metallic), Hg^{1+} (mercurous), and Hg^{2+} (mercuric). The physical and chemical properties of these species differ significantly, as can be seen in Table 2-1, which compares some important properties of elemental mercury, mercuric chloride (an environmentally significant inorganic form), and methylmercury (an environmentally significant organic form).

Table 2-1: Physical and Chemical Properties of Selected Mercury Species[1]

Mercury Species	Elemental Mercury	Mercuric Chloride	Methylmercury*[2]
Formula	Hg	$HgCl_2$	CH_3HgCl
Atomic/Molecular Weight	200.59	271.52	251.10
Density	13.53 @ 25° C	5.4 @ 25° C	3.18 @ 20° C
Vapor Pressure	0.002 mm Hg @ 25° C[3]		0.0085 mm Hg @ 25° C[4]
Melting Point (°C)[5]	-38.87°	276°[6]	170°
Boiling Point (°C)[7]	356.9°	302°[8]	No data
Solubility (grams per liter)[9]	5.6×10^{-5} @ 25°C	69 @ 20°C	0.100 @ 21° C

Metallic mercury is almost unique among metals in that it is a liquid at room temperature.†[10] This fact, along with its relatively high vapor pressure, accounts for the wide dispersal of mercury in the environment.

B. Covalent Bonding with Carbon

Another important property of mercury is its ability to form covalent bonds with carbon. Compounds that consist of an organic functional group covalently bonded to a metal are known as organometallic compounds. They are often highly toxic, and organomercurics are especially so.

* "Because methylmercury exists as a free ion only in minute quantities (Prager, 1997), the chemical and physical data . . . are for the chloride salt." (U.S. EPA Water Quality Criterion for the Protection of Human Health: Methylmercury, 2001.)

† Gallium and Cesium are the only other metals that are liquids at room temperature.

C. Important Mercury Compounds

The best known organomercuric is the very toxic compound methlymercury, which typically occurs as the salts methylmercuric chloride (CH_3HgCl) and methylmercuric hydroxide (CH_3HgOH).[11] The most environmentally significant inorganic mercury salts are mercuric chloride ($HgCl_2$), mercuric hydroxide [$Hg(OH)_2$], and mercuric sulfide or cinnabar (HgS).

D. Solubility of Mercury and Mercury Compounds

The water solubility of the various forms of mercury varies widely. Least soluble is metallic mercury, at 5.6×10^{-5} grams per liter (at 25° C). At 0.100 grams per liter (at 21° C) methylmercury is nearly 2,000 times more water-soluble; still more soluble is mercuric chloride, at 69 grams per liter (at 20° C).[12]

E. Unique Properties

Mercury is unique, in that it:

- Is a liquid at room temperature;
- Forms of covalent bonds; and
- Has a relatively high vapor pressure.

III. The Global Mercury Cycle - Mercury Environmental Fate and Transport

A. The Global Mercury Cycle (Environmental Mercury Fluxes)

The global mercury cycle is described in terms of the flux (movement) of mercury between environmental media. The mercury flux at a given location includes global, regional, and local contributions. Regional and local mercury fluxes vary widely, so it is difficult to generalize about them, but the global cycle (and the contribution of anthropogenic inputs) is well characterized. Studies by Nriagu (1979) and Fitzgerald (1994), summarized in Table 2-2, both conclude that the vast majority of the world's environmental mercury is found in ocean sediments.

Table 2-2: Estimated Mercury Content of Environmental Media – Worldwide[13,14]

	Grams (g) Nriagu (1979)	Grams (g) Fitzgerald (1994)
Ocean Sediments	10^{17}	
Ocean Waters	10^{13}	
Freshwater Sediments	10^{13}	
Biosphere	10^{11}	
Atmosphere	10^{8}	5×10^{9}
Fresh Water	10^{7}	

Some authors have estimated the mercury concentrations in the various environmental media prior to industrialization. However, such estimates are difficult to make, because the current environmental mercury that is of anthropogenic origin is indistinguishable from that which was naturally emitted. The consensus in these studies is that between 40 and 75 percent of the mercury emitted to the atmosphere, worldwide, is of anthropogenic origin.[15] U.S. EPA believes that more study is needed in order to make it possible to distinguish natural mercury fluxes from fluxes of re-emitted anthropogenic mercury.

B. Fate and Transport of Mercury

1. Atmospheric

a. Deposition of Atmospheric Mercury

All atmospheric fluxes of elemental mercury, worldwide, contribute to a global pool of atmospheric mercury as mercury readily evaporates and is transported in air. Recent monitoring of atmospheric mercury levels show that the world's atmospheric burden has increased between two- and five-fold in industrialized times. Studies of Swedish lake sediments, Upper Midwest lakes and peat cores, and remote Alaskan lakes have corroborated these measurements.[16] Much of the mercury emitted to the atmosphere from the oceans is recycled mercury of anthropogenic origin. One study estimates that only 20 to 30 percent of ocean-emitted mercury is of natural origin.[17] A similarly large percentage of terrestrial mercury emissions may be remobilization of anthropogenic mercury.[18]

Before it is ultimately deposited on land or water, either through atmospheric precipitation (wet deposition) or through atmospheric particulate (dry deposition), most atmospheric elemental mercury undergoes oxidization. U.S. EPA mentions two mechanisms for atmospheric oxidation. Most important of these is the oxidation of gaseous elemental mercury to aqueous and particulate-associated divalent mercury (Hg^{+2}) in cloud water. Another (less significant) process mentioned by U.S. EPA is the ozone-mediated oxidation of metallic mercury to divalent mercury, which is then dry-deposited on land or water.[19]

Gas-phase divalent mercury is both reactive and soluble in water. Consequently, this form is "rapidly and efficiently removed by both dry and wet deposition . . . " from the atmosphere. Elemental mercury, on the other hand, is relatively insoluble in water and has a higher vapor pressure; unlike the divalent form, it is "not thought to be susceptible to any major process of direct deposition."[20] U.S. EPA cites a number of studies that describe a minor mechanism for direct deposition of elemental mercury: uptake by the leaves of plants. The studies show that elemental mercury vapor can be taken up by leaves in forest canopies. One study (Hanson, et al., 1994) found that, while such leaf uptake can occur, the net flux of mercury from plants to air is generally higher than that from air to plants. It found that plants can be a net sink for elemental mercury vapor when ambient air mercury concentrations are sufficiently high.[21]

b. Half-life of Mercury in the Atmosphere

Some atmospheric mercury is deposited on land or water relatively near to the emission source, while some enters the global atmospheric mercury cycle, where it is transported to the remotest regions of the earth. The U.S. EPA 1997 Study states that, on average, emitted elemental mercury resides in the atmosphere for one year. By contrast, divalent mercury is deposited relatively quickly, with a residence time as short as a few hours and several months. Consequently, elemental mercury that is emitted to air is distributed worldwide before it is ultimately deposited on land or water, while atmospheric divalent mercury is mostly deposited relatively close to the emission source.[22] Porcella, et al. found that mercuric mercury associated with fine particulates may, like metallic mercury, persist in the atmosphere for up to one year.[23] Because emitted elemental mercury generally persists in the atmosphere for much longer than the oxidized species, global transport and deposition of this form constitute by far the most significant atmospheric mercury flux.[24]

Combustion and incineration are important categories of atmospheric mercury emissions. Stack emissions contain both oxidized and reduced (elemental) mercury. U.S. EPA states that gaseous emissions are thought to contain both forms; while in particulate emissions (soot), oxidized mercury predominates.[25]

2. Terrestrial

Of the environmental media, mercury is least mobile in soil, which “results in soil acting as a large reservoir for anthropogenic mercury emissions.”[26] U.S. EPA states that divalent mercury compounds tend to form immobile complexes with organic matter and minerals in soil. However, it can form soluble complexes with organic ligands and subsequently dissolve in runoff. The current consensus, according to U.S. EPA, is that the rate of deposition of atmospheric mercury on soil greatly exceeds the rate of leaching of mercury from soil.[27] “Mercury that has accumulated in soils may continued to be released to surface waters and other media for long periods of time, possibly hundreds of years.”[28]

Although mercury is less mobile in soil than in water and air, terrestrial mercury can migrate. As noted in Section 1, leaching of mercury from municipal landfills is noted in U.S. EPA's Universal Waste Lamp Rule proposal, in data compiled by DTSC, and in the SWRCB’s Waste Management Unit Database System.

3. Fresh Waters

Methylmercury and divalent mercury can enter freshwater environments by several routes: via wet or dry atmospheric deposition, via runoff from land, and via leaching in groundwater.[29] Once it enters the freshwater environment, divalent mercury can form immobile complexes by the same processes as occur on land.[30] In aquatic environments, both methylmercury and inorganic divalent mercury preferentially partition to soil, sediment, and suspended matter (i.e., dissolved mercury concentration is far lower than the concentration in soil, sediment, and suspended matter).[31] Most mercury in the water column is bound to dissolved organic carbon or bound to suspended particles.[32] According to U.S. EPA, divalent mercury is reduced to the elemental species in the freshwater environment and may subsequently be removed from the water column by volatilization. Studies cited by Mason, et al., show that most such reduction is biologically mediated.[33] However, most of the mercury in the water column is removed not by reduction to the elemental species, but by sedimentation of the particles to which divalent mercury and methylmercury are bound.[34]

The methylation of mercury in aquatic environment is critically important in the global mercury cycle, because methylmercury is an especially bioavailable form of the metal.[35] The biological process by which methylmercury is formed, in conjunction with bioaccumulation and biomagnification of methlymercury in animals that live in contaminated waters and animals that prey upon them, are important components of the biogeochemical mercury cycle. U.S. EPA cites studies that show that methylation can occur both in the water column and in sediments, by both biological and abiotic processes.[36] Jones and Slotton identify several factors that affect the rate of mercury methylation in aquatic sediments. These are summarized in Table 2-3.

Table 2-3: Environmental Influences on the Rate of Methylation of Aquatic Mercury[37]

Environmental Factor	Effect On Mercury Methylation Rate
pH	Methylmercury is produced, transported, accumulated much more efficiently at lower pH.‡
Salinity	Increasing salinity decreases the amount of dissolved mercury, the rate of mercury methylation, and equilibrium methylmercury concentration.
Sulfate Concentration	Sulfate concentration affects the rate of mercury methylation; the maximum rate of methylation is seen when the sulfate concentration is between 200 and 500 mmol.
Oxygen concentration	Production of methylmercury is favored in anaerobic waters, as is its transfer to the food chain.

4. Marine Waters

A large percentage of the earth's mercury is found in oceanic waters and sediments (see Table 2-2). U.S. EPA states that atmospheric mercury, which is mainly in the elemental form, enters the world's oceans primarily by wet deposition.[38] As mentioned earlier, it is thought that elemental mercury is oxidized in the atmosphere. Oxidized mercury is more water-soluble and this property facilitates its deposition into water.[39]

Marine mercury is transformed from one state to another by both biotic and abiotic chemical processes.[40] The U. S. EPA 1997 Study discusses two models of mercury's fate and transport in the ocean. One, developed by Fitzgerald and others, applies to the ocean as a whole; the other, developed by Cossa et al., applies to the waters at the margins of continents.[41]

a. Whole Ocean Model

In the model put forth by Fitzgerald, et al.[42], reactive (e.g., divalent) mercury is first deposited on the ocean's surface. From there, it is transported downward with particles to the anoxic region below the thermocline (the boundary between the warmer, oxygen-rich waters of the surface and the colder, anoxic waters of the depths). As the particles descend, mercury is released and is methylated. Some of the methylmercury then moves to the upper, mixed layer, where it is taken up by organisms at the lowest levels

‡‡ The fact that California's waters have a naturally alkaline pH has mitigated the state's mercury problem somewhat.

of the food web. Some is reduced to the elemental form, by both biotic and abiotic processes, and is subsequently evaded from the water to the atmosphere. In coastal regions, the model assumes that mercury undergoes methylation in sediments and in the water column near the oxycline (defined as the "horizontal boundary layer in the water column, at which dissolved oxygen content changes sharply with depth"[43]).

b. Continental Margin Model

The mercury mass balance model first developed by Cossa, et al. in 1996, identifies river sediments as the largest input of mercury to coastal waters. The model also assumes that coastal waters are subject to higher rates of atmospheric mercury deposition than those of the open ocean, primarily due to nearby emissions of reactive mercury. Another major flux to coastal waters identified in the model is transport of mercury from other parts of the oceans. Three fluxes of mercury from coastal waters are also identified: sedimentation, transport to the open ocean, and evasion to the atmosphere.

The Cossa, et al. model also describes the relative importance of the various methylmercury inputs to coastal waters. These are summarized in Table 2-4.

Table 2-4: Significant Methylmercury Inputs to the World's Coastal Waters[44]

Input to Coastal Waters	MegaMoles per Year (Mmol/yr.)
Upwelling From Other Parts Of The Ocean	0.1 – 0.2
Atmospheric Deposition	0.02
River Systems	0.01
Sediments	0.001

Methylation and Uptake

U.S. EPA describes two marine food webs in which methylmercury bioaccumulation occurs: one in the sediments at the bottom of coastal waters, consisting of larger invertebrates, and one in the water column, made up of plankton.[45] The invertebrates in both of these communities take up methylmercury into their tissues from the surrounding environment.

As is the case in freshwater systems, mercury is believed to be methylated primary in anoxic sediments by sulfur-reducing bacteria. One study cited by U.S. EPA[46] found that a particular species of mussel assimilated particle-bound methylmercury more readily than particle-bound inorganic mercury. Dissolved methylmercury and inorganic mercury were both taken up more efficiently by the mussels than their particle-bound counterparts. However, the authors concluded that particle-bound methylmercury is the major source of the metal in the mussels, because of its much greater abundance in the coastal marine environment than the dissolved form. U.S. EPA cites other studies showing similar uptake mechanisms in other benthic organisms, and transfer of mercury to carnivorous animals that prey on them.[47]

V. Toxicology of Mercury and Mercury Compounds

A. Elemental Mercury[48]

1. Toxicokinetics

Inhalation is the most important route of entry for elemental mercury. About 80 percent of inhaled elemental mercury is absorbed by the body. Once absorbed, the elemental form is distributed throughout the body. Airborne metallic mercury is also absorbed through the skin. The rate of dermal absorption increases with air concentration. The National Academy of Sciences (NAS) states that elemental mercury's average rate of absorption is 0.024 ng/cm^3 for every 1 mg/m^3 in air. The elemental form also "readily crosses the blood-brain and placental barriers," according to NAS. Ingested elemental mercury is poorly absorbed in the digestive tract,[49] and "the majority of the ingested dose is excreted in the feces."[50]

Elemental mercury's half-life in blood is estimated by NAS to be 45 days, but "appears to increase with increasing dose." The metallic form can undergo biotransformation in the body, whereby it is oxidized to the mercuric (Hg^{2+}) form. The metallic form leaves the body in exhaled air, perspiration, and saliva. Metallic mercury that has been biotransformed to the mercuric form is excreted in feces and urine.

2. Toxic Effects[51]

a. Carcinogenicity

The human epidemiological studies that U.S. EPA found in the preparation of the U.S. EPA 1997 Study have major limitations. While none of the studies show a correlation between human exposure to elemental mercury and increased cancer incidence, one shows such a correlation in animals injected with elemental mercury.

b. Neurotoxicity

Neurotoxic effects are elemental mercury's most sensitive toxicological endpoint, in U.S. EPA estimation. U.S. EPA identifies the following neurological symptoms of elemental mercury toxicity:

- Tremors, of the hands and other body parts
- Changeable emotional state, including irritability, extreme shyness, loss of confidence, and nervousness
- Insomnia
- Muscular weakness, atrophy, and twitching
- Headaches
- Sensory loss
- Hyperactive tendon reflexes
- Reduced nerve conduction velocities
- Memory loss
- Impaired cognitive function

c. Renal Toxicity

U.S. EPA states that toxic effects are seen in the kidneys at higher exposure concentrations than those required to produce neurotoxic effects.

d. Pulmonary Toxicity

U.S. EPA also states that toxic effects are seen in the lungs at higher exposure concentrations than those required to produce neurotoxic effects.

e. Reproductive Toxicity

U.S. EPA identified some studies suggesting that elemental mercury may cause reproductive toxicity. In two of these studies, behavioral changes were noted in rats that were exposed to elemental mercury *in utero* and around the time of birth.

f. Cardiovascular Toxicity[52]

U.S. EPA identifies several manifestations of the cardiovascular toxicity of elemental mercury. It is unclear from the literature, according to U.S. EPA, whether elemental mercury directly causes toxicity to the heart, or whether the observed effects result from elemental mercury's neurotoxicity. The effects include:

- Tachycardia
- Elevated blood pressure
- Heart palpitations

3. Reference Exposure Standards

a. U.S. EPA Reference Doses

U.S. EPA has developed limits for exposure to hazardous substances, known the Reference Dose (RfD) and Reference Concentration (RfC). These terms are defined on the Internet web site for U.S. EPA's Integrated Risk Information System (IRIS) as follows[53]:

> RfC: An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It can be derived from a No Observed Adverse Effects Level (NOAEL), Lowest Observed Adverse Effects Level (LOAEL), or benchmark concentration, with uncertainty factors generally applied to reflect limitations of the data used. Generally used in U.S. EPA 's noncancer health assessments.
> RfD: An estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It can be derived from a NOAEL, LOAEL, or benchmark dose, with uncertainty factors generally applied to reflect limitations of the data used. Generally used in U.S. EPA's noncancer health assessments.

Reference doses and concentrations are used in risk assessments to determine public health and environmental impacts through air, water and soil exposure routes through inhalation and ingestion. Table 2-5 summarizes the RfC that has been established for elemental mercury.

Table 2-5: Reference Doses (RfDs) and Reference Concentrations (RfCs) for Mercury, Elemental [54]

SUBSTANCE NAME	EXPOSURE ROUTE	DURATION OF EXPOSURE	TEST SPECIES	RFC (MG/M^3)	RFD (MG/KG-DAY)
Mercury, Elemental	Inhalation	Chronic	Human occupational studies	0.0003	Not available at this time.

b. Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Levels (MRLs) for Hazardous Substances[55]

In response to a mandate in the Superfund Amendments and Reauthorization Act (SARA) of 1990, ATSDR has developed MRLs for hazardous substances commonly found at facilities on the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) National Priorities List (NPL). An MRL is an estimate of the highest exposure to a hazardous substance that is not likely to pose significant health risks over a given period of exposure. Inhalation MRLs are stated units of parts per million (ppm) or milligrams per cubic meter (mg/m^3). Oral MRLs are in units of milligrams per kilogram body weight per day (mg/kg/day). The MRL values established by ATSDR for metallic mercury are summarized in table 2-6.

Table 2-6: Minimal Risk Levels (MRLs) for Mercury, Metallic -- March 1996[56]

SUBSTANCE NAME	EXPOSURE ROUTE	DURATION OF EXPOSURE	TOXIC ENDPOINT	MRL VALUE
Mercury, Metallic	Inhalation	Acute	Developmental	0.00002 mg/m3
Mercury, Metallic	Inhalation	Chronic	Neurological	0.000014 mg/m3

The number and range of health reference standards along with their corresponding low acceptable daily doses illustrate the toxic nature of mercury.

B. Mercuric Mercury

1. Toxicokinetics

Mercuric mercury can enter the body via inhalation, ingestion, or dermal exposure. Aerosols of mercuric mercury can be absorbed through the lungs, but NAS does not provide data for the efficiency of absorption by this route. NAS estimates that the efficiency of absorption of ingested divalent mercury is between 7 and 15 percent and that the efficiency of dermal absorption in guinea pigs is in the 2 to 3 percent range.

The divalent form tends to concentrate in the kidneys in adults, and the amount retained depends on the dose. In exposed newborns however, it does not concentrate in the kidneys, but rather is distributed throughout the body. Mercuric mercury, unlike the elemental form, does not easily cross the blood-brain or placental barriers. Any mercuric mercury that does cross the placenta can enter the brains of fetuses and neonates more readily than those of older children and adults, due to the incomplete formation of the blood-brain barrier. Mercuric mercury has a blood half-life of that ranges from 19.7 to 65.6 days, according to NAS.

NAS cites evidence that mercuric mercury can undergo biotransformation. They mention an experimental study in which elemental mercury vapor was found to be exhaled by rodents after they were orally administered mercuric mercury. NAS also states that, while mercuric mercury does not undergo methylation in body tissues, it is methylated by gastrointestinal microbes. The routes of excretion of the mercuric form are via urine, feces, saliva, bile, sweat, air, and breast milk.

2. Toxic Effects[57]

a. Carcinogenicity

U. S. EPA identified no studies suggesting mercuric chloride is carcinogenic in humans. However, some studies in which rodents that were force-fed mercuric chloride showed increased incidence of certain tumors in exposed rats.

b. Renal Toxicity

The most sensitive toxic endpoint in humans exposed to inorganic mercury is autoimmune glomerularnephritis, according to U. S. EPA. This inflammation of the kidney results from the mercury-induced formation of antibodies to the basement membrane of the glomeruli.

c. Reproductive Toxicity

U.S. EPA found studies suggesting exposure to inorganic mercury salts may result in reproductive toxicity, but believes these studies are flawed.

3. Reference Exposure Standards

Tables 2-7 and 2-8, respectively, summarize the RfD and MRLs that have been established for mercuric chloride.

Table 2-7: Reference Doses (RfDs) and Reference Concentrations (RfCs) for Mercuric Chloride[58]

SUBSTANCE NAME	EXPOSURE ROUTE	DURATION OF EXPOSURE	TEST SPECIES	RFC (MG/M^3)	RFD (MG/KG-DAY)
Mercuric Chloride	Oral	Chronic	Brown Norway rat	Not available at this time.	0.0003

Table 2-8: Minimal Risk Levels (MRLs) for Mercury, Inorganic -- March 1996[59]

SUBSTANCE NAME	EXPOSURE ROUTE	DURATION OF EXPOSURE	TOXIC ENDPOINT	MRL VALUE
Mercury, Inorganic	Oral	Acute	Renal/Urinary	0.007 mg/kg/day
Mercury, Inorganic	Oral	Intermediate	Renal/Urinary	0.002 mg/kg/day

Discussion of reference doses and MRLs are found above in metallic mercury section. In contrast to metallic mercury, inorganic mercury's reference dose is based on the oral route of exposure rather than inhalation route. The exposure potential of these two forms of mercury differ in that the inhalation of metallic mercury is unlikely to occur outside an occupational setting. Furthermore, metallic mercury is poorly absorbed in the digestive tract, whereas inorganic mercury's rate of absorption is higher, as discussed above.

C. Methylmercury

1. Toxicokinetics

According to NAS, inhaled methylmercury vapors can be absorbed by the lungs. Methylmercury is also well absorbed in the gastrointestinal tract; humans absorb 95 percent of the methylmercury in fish they consume, according to NAS. In experiments with guinea pigs, 3 to 5 percent of dermally applied methylmercury was absorbed within 5 hours.

Up to 10 percent of absorbed methylmercury is distributed to the blood, and 90 percent of this 10 percent resides in red blood cells. Methylmercury is lipophilic and readily crosses the blood-brain and placental barriers.

Methylmercury's half-life in blood is estimated to be 50 days. Its blood half-life is reduced in lactating females. Methylmercury's half life in the body is estimated to be from 70 to 80 days, depending on the species, strain, and sex of the experimental animal being studied, as well as the dose administered. It slowly undergoes biotransformation and is converted to the mercuric form by an unknown mechanism. Bile and feces are the important routes of methylmercury excretion, most of which is in the mercuric form.

2. Toxic effects[60]

U. S. EPA notes that, in human and animal studies, there is often a delayed onset of the symptoms of methylmercury toxicity, which may be attributable to metabolic changes. For example, in the 1956 Minamata Bay incident, the victims were exposed to high levels of methylmercury, but did not exhibit signs or symptoms of mercury toxicity for several years.[61]

a. Carcinogenicity

U. S. EPA identified a number of epidemiological studies that analyzed the correlation between methylmercury exposure and human carcinogenesis. They are of the opinion that these studies were seriously flawed. However, evidence of carcinogenicity was seen in some rodent studies that U. S. EPA identified. Kidney tumors were observed in orally exposed mice, but only when other signs of severe nephrotoxicity were also observed.

b. Neurotoxicity

U. S. EPA identifies the nervous system as the "critical target for methylmercury toxicity."[62] Neurotoxic symptoms that occur in neonates are identified below, under the heading “Reproductive Toxicity”. In adults, methylmercury neurotoxicity is characterized by “multiple central nervous system effects.”[63] These include:

- Ataxia (impairment of voluntary muscle coordination)
- Paresthesia (tingling sensations)

c. Reproductive Toxicity[64]

Studies identified by U. S. EPA show methylmercury exposure to cause chromosomal aberrations. Both human and animal studies show that methylmercury exposure causes developmental toxicity. According to U. S. EPA, the most sensitive toxic endpoint in offspring of mothers exposed to methylmercury is neurotoxicity, which can occur in the offspring whether or not any symptoms occurred in the mother during gestation. Manifestations identified by U. S. EPA include:

- Delayed onset of walking
- Delayed onset of talking
- Cerebral palsy
- Altered muscle tone and deep tendon reflexes
- Reduced neurological test scores

3. Reference Exposure Standards

Tables 2-9 and 2-10, respectively, summarize the RfD and MRLs that have been established for methylmercury.

Table 2-9: Reference Doses (RfDs) and Reverence Concentrations (RfCs) for Methylmercury[65]

SUBSTANCE NAME	EXPOSURE ROUTE	DURATION OF EXPOSURE	TEST SPECIES	RFC (MG/M^3)	RFD (MG/KG-DAY)
Methylmercury	Oral	Chronic	Human epidemiological studies	Not available at this time.	0.0001

Table 2-10: Minimal Risk Levels (MRLs) for Methylmercuric Chloride -- March 1996[66]

SUBSTANCE NAME	EXPOSURE ROUTE	DURATION OF EXPOSURE	TOXIC ENDPOINT	MRL VALUE
Methylmercuric Chloride	Oral	Acute	Developmental	0.00012 mg/kg/day
Methylmercuric Chloride	Oral	Intermediate	Developmental	0.00012 mg/kg/day

4. Bioaccumulation

Contributing factors to methylmercury bioaccumulation are its lipophilic properties, ready absorption in the gastrointestinal tract, and long half-life in the body. “Nearly 100 percent of the mercury that bioaccumulates in fish tissue is methylmercury.”[67]

Inorganic and elemental mercury are both toxic, but of the environmentally important forms, methylmercury poses the greatest risk to human health and the environment.

This is due both to methylmercury's high toxicity, and the fact that consumption of contaminated fish is the primary route of mercury exposure in humans.[68] Of the oral routes, methylmercury's poses the greatest risk to humans in non-occupational settings. While metallic mercury has lower reference doses, these are based on the inhalation route of exposure, which is encountered mostly in occupational settings.

Section 2 Key Points:

- Three important forms of mercury exist in the environment: metallic mercury, mercuric mercury, and methylmercury; each has distinct chemical and physical properties, environmental behavior, and toxicology.
- Up to 75 percent of the mercury emitted to the world's atmosphere is of anthropogenic origin, and the world's atmospheric mercury load has increased between two and five-fold since industrialization.
- Mercury is methylated in both the water phase and in sediments.
- Methyl mercury bioaccumulates in the marine food web, both in the water column and in sediments.
- Inhalation is the most important absorption route for elemental mercury, and neurotoxic effects are its most sensitive toxicological endpoint.
- Mercuric mercury enters the body via inhalation, ingestion, or dermal exposure, and can be methylated by gastrointestinal microbes.
- Methylmercury is a potent developmental and neurological toxin in humans.
- Methylmercury is well absorbed in the digestive tract.
- Consumption of contaminated fish is the primary route of human methylmercury exposure in humans.

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Section 3: Sources of Mercury in California's Environment

I. Introduction

This section reviews the sources of mercury in California's environment. It lists important natural emission sources, and discusses anthropogenic sources in more detail. Where data is available, the amount of mercury released or the annual emission rate from a particular source is estimated. Comprehensive data for releases of mercury is not available, so this section gives only a qualitative picture. However, the qualitative information in this section gives an appreciation for the number and diversity of the State's mercury emission sources. Section 4 discusses the uses of mercury, including its addition to products, in more detail.

II. Natural Sources

The mercury found in the environment originates from both natural and anthropogenic sources. Both of these types of sources contribute to environmental mercury loading. Natural mercury releases to the atmosphere include*:

- Volcanic emissions
- Continental degassing
- Coastal atmospheric input
- Oceanic emissions
- Vapors and particles emitted from land biota

Natural mercury releases to land and water include:

- Atmospheric deposition
- Coastal atmospheric depositions
- Oceanic and polar deposition
- Dead biota

III. Anthropogenic Sources

When identifying the anthropogenic sources of mercury in California, it is pertinent to discuss both historical and current activities that introduce mercury into the environment, because once emitted, mercury persists there. It should be noted that California is atypical in that some of the largest point source categories identified in U.S. EPA's Mercury Study Report to Congress (U.S. EPA 1997 Study) are either less significant here than in the United States as a whole, or do not exist at all.

A. Air Emission Sources in California

The California ARB's 2000 emission inventory estimates that there were approximately 27,500 pounds of mercury emitted to California's atmosphere. The principal sources include windblown dust, geothermal power generation, cement manufacturing, petroleum product manufacturing, electric utilities (other than geothermal sources), mineral processes, waste burning, incineration, and fluorescent tube breakage. Table 3-1 lists in decreasing order of emissions the sources of mercury air emissions for the

* As previously noted in Section 1, a significant amount of the mercury emitted to the atmosphere from the earth's oceans and crust is re-emitted anthropogenic mercury that was previously deposited.

2000 inventory year.

Table 3-1: Air Emissions of Mercury in California in 2000

SOURCE OF MERCURY	EMISSIONS (LBS/YR)	EMISSIONS (% OF TOTAL)
Windblown Dust	18,017.86	65.5
Geothermal	2,072.27	7.5
Cement Manufacturing	1,730.45	6.3
Petroleum-related Mfg.	1,600.02	5.8
Electric Utilities	839.38	3.1
Mineral Processes	592.86	2.1
Waste Burning	546.37	2.0
Other Industrial Processes	537.02	1.9
General Manufacturing	521.87	1.9
Fluorescent Tube Breakage	416.00	1.5
Incinerators	269.71	0.9
Metal Processes	122.09	0.5
Food and Agriculture	49.55	0.3
Services and Commercial	48.80	0.2
Degreasing/Coatings/Print	35.52	0.1
Other (fuel combustion)	28.47	0.1
Sewage Treatment	18.10	0.06
Wildfires	10.18	0.03
Cogeneration	8.13	0.03
Landfills	0.38	0.001
Soil Remediation	0.35	0.001
Other (waste disposal)	0.03	0.000
Total	**27,465.41**	

The sources associated with the highest emissions of mercury are discussed as follows:

1. Windblown Dust

Windblown dust is the largest single source of mercury emissions to the air in California in 2000. There were approximately 18,000 pounds of mercury emitted to the air in 2000. As a source category, windblown dust is made up of many, more specific, subcategories, all of them associated with human activity. Sources of windblown dust include farming operations, construction, and paved and unpaved road dust.

2. Geothermal Energy Production

Geothermal power is an important source of energy in a number of counties in California. Generally, a turbine is turned by steam that is generated deep in the Earth. As a result of its contact with mercury-rich soils, the steam used to drive geothermal turbines contains mercury. As the steam is off-gassed to the atmosphere, the mercury is carried with it. Geothermal sources are California's second largest source of mercury emissions to the atmosphere. The ARB estimates that approximately 2,000 pounds of mercury were emitted to the air in 2000.

3. Cement Manufacturing

Cement manufacturing is the third largest source of mercury emissions to air in California in 2000 with approximately 1,700 pounds associated with it. The major processes responsible for emissions of mercury are the dry process kilns and raw material handling. Some cement manufacturers may accept waste for cogeneration.

4. Petroleum-Related Manufacturing

Petroleum-related manufacturing sources include oil and gas exploration, petroleum refining, and petroleum marketing. These source categories accounted for approximately 1,600 pounds of mercury associated with them for the 2000 inventory year.

5. Electric Utilities

Electric power production accounts for approximately 850 pounds of mercury emissions to air. Most of these emissions are associated with the use of municipal waste as fuel. Coal combustion also accounts for a large portion of the mercury emitted from this source category.

6. Mineral Processes

Processes such a gold mining, asphaltic concrete production, and quarrying operations emitted approximately 600 pounds of mercury.

7. Waste Burning

There are approximately 550 pounds of mercury emitted to the air from agricultural burning, range improvement, and weed abatement.

8. Other Industrial Processes

Aerospace coatings, cotton ginning, and chemical manufacturing are the largest subcategories of this general source category, which accounted for approximately 525 pounds of mercury air emissions.

9. Manufacturing Processes

This category includes the combustion processes associated with manufacturing. Boilers, process heaters, and space heaters associated with manufacturing account for approximately 525 pounds of mercury emitted to the air.

10. Fluorescent Tube Breakage

This is a source that the ARB became aware of only recently. Consequently, the estimate of mercury emissions from this source is based on California's proportion of the total population of the United States. This corresponds to a release of approximately 410 pounds of mercury in California in 1989. At the time of the publication of the U.S. EPA 1997 Study, EPA predicted that mercury emissions from the breakage of used lamps would decrease. The primary reason for this prediction was a trend to reduce the amount of mercury used in the manufacture of fluorescent tubes. The U.S. EPA 1997 Study states that the mercury content of the average fluorescent lamp was cut from 48.2 mg in the mid-1980s to 22.8 mg in 1997. More recently, the amount of mercury in the average lamp has been reduced to approximately 10 mg. The reduction in the mercury content of each lamp is likely offset somewhat by increases in the sales and use of fluorescent lamps that have resulted from the continuing energy crisis in California.

11. Other Sources of Mercury Air Emissions

In addition to the ten sources listed above, there are a number of other sources that emit mercury to the air. Those include incineration, metal processes, food and agriculture, commercial, degreasing, sewage treatment, wildfires, cogeneration, landfills (fugitive emissions and landfill gas), and soil remediation. These processes account for approximately 600 pounds of mercury emitted to the air in the 2000 inventory.

B. Temporal and Spatial Variability of Mercury Air Emissions

When evaluating the potential health impacts of the emissions of any substance of interest, the ARB includes an evaluation of temporal and special factors. These include factors such as, whether the emissions occur seasonally; the frequency of the emissions, such as occasional, daily, or on going events; and the locale (urban or rural) of the emissions.

Although windblown dust accounts for approximately 65 percent of the total mercury emissions statewide, the majority of the emissions occur during the spring, summer, and early fall and occur in rural settings. The potential health impacts from this source are probably low—not to be ignored, but low. Although the emissions from geothermal sources occur on a daily basis, they too are primarily in a rural setting. The potential health impacts are probably low, but the fact that they occur daily would lead the ARB to pay more attention to those emissions than those associated with windblown dust.

C. Water Mercury Sources

1. Past Activities - Legacy Waste

a. Placer Gold Mining--Sierra Nevada

Much of California's environmental mercury burden is a result of its natural mineral resources and of past activities to recover them. Mercury's tendency to form amalgams has long been used in gold mining as a means to improve gold recovery. Mercury is added to the riffles in large sluices, through which a slurry of gold-containing sediment and water is passed. The lighter gravel and sand is washed out of the sluice, while the gold particles and mercury form an amalgam, which is left behind. Significant amounts of the mercury used in the sluices can be lost to the environment over time, via leaks and in tailings.[1] The use of mercury in gold mining in the United States has been largely phased out, however the practice is still widely followed in many less-developed regions of the world (although it is illegal in most countries).[2]

Large-scale hydraulic (placer) gold mining began in the 1850s in the northern Sierra Nevada and continued until the 1950s in the Klamath-Trinity Mountains; large amounts of mercury were used to increase the recovery of gold from river sediments.[3] By some estimates, between 1500 and 4000 short tons of mercury were released to the rivers and streams of these regions in the course of this gold mining.[4, 5] These 'legacy' mining wastes continue to contaminate the rivers and streams where gold was mined, and mercury continues to be recovered by contemporary dredge miners.[6] Most of the Sierra Nevada's rivers have since been dammed, and studies have shown that the majority of the legacy mercury in these rivers is intercepted by the reservoirs created by their dams.[7]

b. Coast Range Mercury Mining

California's coast range, the source of most of the mercury used in placer gold mining, "contains one of the world's great geologic deposits of mercury."[8] The mercury mines of the coast range made the area one of the world's most productive sources of the metal, before the cessation of mining in the area.[9] By one estimate, "more than 300 abandoned mercury mines and prospects can now be found along the California Coast Range."[10] In 1990, the last operating mercury mine in the United States closed; in 1996, only a small amount of primary (from ore) mercury continued to be produced, as a byproduct of gold mining.[11] One of the gold mines that continues to produce mercury is located in California: the McLaughlin mine in Napa.[12]

In spite of their closure, drainage from the coast range's numerous abandoned mercury mines continues to be a major source of mercury contamination in the area's water bodies.[13] Sulfur in the piles of tailings in the area reacts with oxygen and rainwater to form sulfuric acid, which readily dissolves mercury in the ore and carries it into creeks.[14]

One study found that more than 80 percent of the dissolved mercury in Marsh Creek -- a small coast range creek -- could be traced to a single pile of exposed tailings at an abandoned mercury mine site.[15]

2. Current Activities

a. Publicly Owned Treatment Works (POTWs) Effluents[16]

Publicly owned treatment works (POTWs) have been identified as a source of mercury discharges to the State's waters. The San Francisco Bay RWQCB has identified San Francisco Bay Area POTWs as small but quantifiable sources of mercury discharges, accounting for 15 kg mercury per year, or less than 1 percent of all mercury loadings to the San Francisco Bay. While it is technologically difficult to attain mercury concentrations much lower than 5-7 ng/L in advanced treatment plants, and 15-25 ng/L in secondary plants, the overall removal efficiency of the plants is quite high. Comparison of influent to effluent concentrations shows that treatment plants typically remove greater than 90 percent of mercury loadings to the plant before discharge.

Since POTWs are already removing the large majority of the mercury in their influents, and since Bay Area POTWs overall have extremely good performance, San Francisco Bay RWQCB believes the best way to achieve additional reductions in mercury loadings is through pollution prevention actions targeted at reducing influent concentrations.

D. Land Mercury Sources

1. Past Activities

a. Legacy Waste

As discussed earlier, historical gold mining in the Sierra Nevada and mercury mining in the Coast Range led to water contamination in both areas. Mining activities also caused direct land contamination with mercury in tailings and in process wastes that were left at ore processing sites. While the mercury may have been indigenous to some mining areas, mining and enrichment activities altered its chemical and physical state, and increased its potential for movement into water and air. Direct (acute exposure) or indirect contact (bioaccumulation in the food chain) with this “legacy” mercury continues to pose risks to public health and the environment.

b. Past Disposal Of Products Containing Mercury

The use of mercury in products was more common in the past than now, and direct land contamination incidental to their manufacture, use, breakage and disposal was, consequently, higher. Industrial process wastes were not tightly controlled until the mid-1980s; they were previously disposed by open dumping, open burning, and collection in unlined ponds, sumps, and lagoons. For most of human history, engineering controls to reduce migration of waste from land to other environmental were unknown. All of these factors have contributed to California’s contaminated land sites, some of which are part of DTSC’s CalSites database.†

c. Past Air Emissions of Mercury

Because mercury is transitory in air and is ultimately deposited either on land or in water, past air emissions from gold mining, open garbage burning, and other activities have contributed to mercury land contamination. As noted in Section 2, air-emitted mercury may be deposited relatively quickly near the emission source, or it may persist in the atmosphere for between several months and one year, depending on its chemical state.

2. Current Activities

a. Air Emission Contribution

Eventually, all of the mercury emitted by these activities will be deposited on land or in water, as noted previously. While many of the human activities that emit mercury to air have ceased, others continue to contribute to air loading and ultimately, to land loading of the metal. Since 1989, ARB has required the operators of all facilities that meet certain criteria to report their mercury emissions. ARB tracks this data by Standard Industrial Classifications (SIC). According to ARB, several industrial categories have facilities that emit more than 100 pounds of mercury per year. These SIC include: crop preparation services, gold ores, crude petroleum and natural gas, petroleum refining, petroleum and coal products, sawmills and planing mills, hydraulic cement operations, clay refractories, refuse systems, government, and electric services.

† As noted in Section 1, the CalSites database should not be considered the sole database for identification of mercury-contaminated sites in California.

b. Waste Disposal

Controls over hazardous waste disposal were initiated by both State and federal regulations in the mid-1980s to limit the amount of anthropogenic mercury contained in industrial and consumer wastes that are disposed in landfills. Both State and federal regulations contain criteria to determine whether a waste is hazardous, which in turn determine its proper management and disposal. In California, land disposal of hazardous waste is restricted to hazardous waste (Class I) landfills for, while disposal of nonhazardous waste is limited to municipal (Class III) landfills and at some designated waste (Class II) landfills.

The landfill disposal of mercury-containing waste leads to both direct land contamination and the potential for leaching and surface runoff of mercury into lakes, rivers and streams. While direct land contamination cannot be avoided, the leaching potential can be controlled. Class I landfills are required to have leachate collection systems and to meet stringent siting and design criteria. All new Class III landfills are designed to meet federal design specifications found in Subtitle D of the Resource Conservation and Recovery Act (RCRA), including requirements for base liners and leachate collection systems. However, the majority of California's Class II and III landfills were constructed prior to the adoption of this requirement and therefore do not have leachate collection systems.

Legislation adopted in 1984 (Chapter 1532, Statutes of 1984) required groundwater testing at all solid waste (Class III) landfills, and the ranking of the water quality threats posed by each site in a Solid Waste Assessment Test (SWAT) report. A report from the SWRCB to the CIWMB summarized the data from the 544 sites thought most likely to have leaked hazardous wastes into the waters of the State. Only 8 percent of these landfills were lined. While the majority (between 72 percent and 86 percent) were found to be "leaking waste constituents outside the limits of the landfill,"[17] none was found to have leakage of mercury above "beneficial use" criteria.[18]

Data in the U.S. EPA 1997 Report suggests that, nationwide, landfills are a relatively minor source of atmospheric mercury emissions.[19] However, in recent studies of landfill gas from a Florida municipal landfill, elemental mercury, methylmercury, and dimethylmercury were detected a relatively high levels, suggesting that landfills may be a larger air emission source than was previously believed.[20]

In 1993, the CIWMB adopted regulations that "revised the State's solid waste landfill regulatory program in partnership with local enforcement agencies and the State Water Resources Control Board to achieve federal approval under Subtitle D."[21] These regulations require landfills to collect landfill gas in wells. From there, gas is conveyed either to a small electric power plant or to a flare, where it is burned.

According to CIWMB's 2000 Annual Report, the State has approximately 275 solid waste landfills. About half of these are equipped with landfill gas collection systems.[22] Due to mercury's volatility, gas that is produced in landfills not equipped to collect it is presumably evaded directly to the air. In landfills equipped to collect landfill gas, mercury would most likely also be released to air during the combustion of the gas, whether in flares or small power plants.

The amount of mercury potentially entering waste stream has declined in recent years, due largely to the fact that the use of mercury in a number of common products was banned during the 1990's. (The use of mercury in household batteries and paints has been eliminated, for example.) However, more than twice as much mercury was deposited in landfills as was emitted to air in 1996 (325 short tons vs. 159 short tons) according to USGS.[23]

Industrial wastes, as well as products containing mercury, enter the waste stream for land disposal. Section 4 contains a compilation of mercury-containing products and their uses. Some products that could potentially be sources of environmental contamination when disposed, include:

- fluorescent tubes;
- mercury switches;
- button batteries;
- fever thermometers;
- laboratory thermometers, manometers, etc.;
- dental amalgam;
- old mirrors;
- old felt;
- old textiles; and
- old mercury-containing paints.

1) Hazardous Waste

One of the criteria for determining whether a mercury-containing waste is hazardous is based on the concentration of mercury present in the waste. California has established criteria for both the total and soluble concentrations of mercury in waste. To determine the soluble concentration, the waste is subjected to a procedure, the WET, designed to mimic the leaching that occurs in landfills. The sample extract from the WET is analyzed, and the dissolved mercury concentration is determined. If its mercury concentration equals or exceeds 0.2 mg/L, or if the waste's total mercury concentration equals or exceeds 20 mg/kg, the waste is determined to be hazardous.

A number of products are generally presumed be hazardous waste when disposed, due to their mercury content. They include most fluorescent lamps (which exceed hazardous waste identification criteria due to the relatively light weight of the glass an metal components), thermometers, dental amalgam, certain batteries, and mercury switches. Depending on the weight of their non-mercury components, barometers and manometers, may also be classified as hazardous waste when discarded.

2) Nonhazardous Waste

Other Waste Sources - Products with Intentionally-Added Mercury

Some household appliances and most automobiles contain mercury switches, but due to the small amount of mercury relative to the large mass of an appliance or car, they often do not exceed hazardous waste concentration thresholds for mercury. While non-hazardous household appliances and automobiles may be disposed in Class III landfills, most are recycled to reclaim their metal. In response to recyclers' widespread practice of shredding and crushing appliances and autos without removing hazardous components, AB 847 (Chapter 884, Statutes of 1997) added a requirement that such components, including mercury switches, be removed from appliances (but not from automobiles) prior to crushing them or transferring them to a baler or shredder for recycling.

Because their mercury switches are still not generally removed from recycled automobiles, the nonmetallic, non-recycled components of shredded automobiles are commonly contaminated with mercury. Recently, DTSC has undertaken a project to analyze samples of this residue, known as 'auto shredder fluff' for inorganic contaminants, including mercury. Previously, DTSC reclassified treated auto shredder fluff (which would otherwise be regulated as hazardous waste) as nonhazardous because it was determined to exhibit "a mitigating physical or chemical property." Treated fluff is currently being used as daily cover in some Class III landfills.

Senate Bill 633 (Sher, 2001), was recently chaptered on October 10, 2001 and requires mercury-containing switches that are voluntarily removed from motor vehicles to be managed in accordance with DTSC's universal waste rule. DTSC and local agencies to would be required by the bill to provide coordinated technical assistance to businesses in the "safe removal and proper disposal of mercury-containing light switches from motor vehicles." The bill would also mandate DTSC to coordinate and encourage replacement and recycling of mercury-containing motor vehicle light switches.

Other mercury-containing wastes that are currently disposed in Class III landfills include:

- nonhazardous waste mercury-containing lamps,
- hazardous waste fluorescent lamps generated by households and small-quantity generators,
- soils,
- industrial wastes,
- ash,
- POTW sludges, and
- cleanup residues or mixtures of these wastes from spills and leaks.

Section 3 Key Points:

- Mercury found in the environment originates from both natural and anthropogenic sources.
- Mercury released into the environment in the past continues to be move in the global mercury cycle.
- Important historical sources of mercury releases to land, air, and water include gold and mercury mining and garbage burning.
- Many sources of mercury air emissions exist; by far the largest is the windblown dust.
- More than 300 abandoned mercury mines and prospects can now be found along the California Coast Range.
- POTWs are the source of small but quantifiable mercury discharges to the State’s waters.
- Land disposal of mercury-containing wastes contributes to California’s environmental mercury loading.
- The use of mercury in a number of common products was banned in the 1990s, and further restrictions are under consideration.

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Section 4: Mercury-Containing Products, Uses, and Alternatives

I. Introduction

Mercury's physical properties, including its high density and liquid state at room temperature make it useful in mechanical switching devices such as thermostats. As a liquid metal, it readily amalgamates with other metals, making it useful in mining and as a durable tooth filling. As mercury's temperature increases, its volume increases, giving rise to its use in thermometers. Elemental mercury also has a bright and reflective property, making it a useful component in early mirror manufacture. Additionally, because mercury's toxic properties make it an effective biocide, mercury compounds have been used in various pest control agents.

In most applications, manufacturers appear to be reducing or eliminating mercury. However, it is still used when it is considered essential or when there is no economical alternative. Despite the decrease in mercury consumption, significant releases to the environment are expected to continue as spent mercury-containing products are disposed.

There is a growing list of viable alternatives for mercury products. Some alternatives require changes in consumer behavior. Consumers can effect changes in mercury content by avoiding products such as shoes with blinking lights. They may also choose to use composite fillings over amalgam.

A compilation of major mercury products, their uses, and alternatives is presented below. The compilation includes both current and past uses and products, as many past mercury-containing products continue to be significant constituents of the solid waste stream today.

II. Mercury-Containing Products and Alternatives

A. Measurement Devices—Temperature

In 1714, the German-born physicist Daniel Gabriel Fahrenheit invented the mercury thermometer[1], making use of mercury's relatively constant rate of thermal expansion. Mercury thermometers have remained in wide use for almost 300 years since.

1. Alternatives

In recent years, as awareness of the health and environmental hazards of mercury has increased, the use of mercury thermometers has been reduced, in favor of less hazardous alternatives. Several States, including California, have introduced legislation in 2001 that would restrict, ban, or phase-out mercury products, including the manufacture and sale of mercury fever thermometers.[2] Even medical uses of mercury thermometers have recently come under scrutiny. The July 2001 issue of *Pediatrics,* a publication of the American Academy of Pediatrics, contains an article that supports elimination of mercury-containing thermometers.

Several types of non-mercury glass thermometers are commercially available.

Digital (electronic), “plastic tape or strip” (heat-sensitive color-change), and ear canal infrared thermometers are easier to use than mercury thermometers, and they are mercury free.[3] They also avoid the risks of broken glass, subsequent mercury exposure, and cleanup and disposal costs.

Digital thermometers are more costly than mercury thermometers. Although the thermometer itself is mercury-free, the button batteries that are required for operating it may contain mercury. Alkaline-manganese, zinc-air and silver oxide batteries may only contain up to 25 mg mercury by law. A typical glass thermometer contains approximately 500-mg mercury, has a few years of life in medical office/hospital use, and many years of life in household use. Because electronic thermometer batteries require periodic replacement, its life-cycle mercury consumption may approximate the traditional mercury thermometer. Its advantage is that there are no mercury spills to clean up. Because alcohol-filled thermometers and “plastic strip” thermometers are available, the digital thermometer may be preferred only if mercury-free batteries or battery recycling options are easily available. Plastic strip thermometers may be less accurate, but they are adequate as a household-screening tool.

The alcohol-based thermometer contains a red- or blue-dyed alcohol. Glass thermometers containing alcohol are commonly used for indoor/outdoor thermometers. Alcohol-based thermometers should not result in any contamination issues and are relatively low cost. Manufacturers have indicated that alcohol-based thermometers are currently unsuitable for medical use because their accuracy is limited.[4]

The galinstan thermometer contains a mixture of gallium, indium, and tin that is similar to mercury in appearance. The galinstan thermometer is not in wide distribution and may be more difficult to reset. Because it looks like a mercury-containing thermometer, it can potentially hinder mercury recycling by contaminating the mercury waste stream if they are placed in broad use and are not carefully segregated. Moreover, if disposed in significant amounts, gallium, indium, and tin may also become contaminants in the environment.

B. Measurement Devices—Pressure

Mercury’s liquid state, density, and low surface tension make it useful in devices such as manometers (used to measure pressure differences), barometers (used to measure atmospheric pressure), and sphygmomanometers (used to measure blood pressure).[5]

C. Electrical Devices – Switches and Thermostats

Mercury’s electrical conductivity and liquid state make it useful in switches that control electrical devices. Mercury switches are used in thermostats and other devices because they are simple, reliable, durable, maintenance-free, and are relatively low-cost to manufacture. Mercury is contained in basically two types of switches: tilt and reed. "Mercury tilt switches are small tubes with electrical contacts at one end of the tube. As the tube tilts, the mercury collects at the lower end, providing a conductive path to complete the circuit. When the switch is tilted back, the circuit is broken."[6] Mercury tilt switches have been used in light switches, thermostats, off-balance switches in household appliances, trunk light switches in automobiles, thermocouples, among others. Reed switches are usually found in sealed electrical switch relays. The reeds in these switches are the contacts and are sometimes coated with mercury to provide a reliable electrical contact. Other electrical devices that contain mercury include some batteries, toys, games, and novelty items such as some shoes with blinking lights.

1. Alternatives [7] [8] [9]

There are a wide variety of switch designs that do not use mercury. These include pendulums, ball bearings, hard contacts, magnetic, inductive, and photoelectric switches. The use of hard contact switches, which are used in most car doors, in place of mercury-containing tilt switches in car trunk lids, is a good use of an alternative.

Solid-state thermostats, particularly digital models, have become available as an economical alternative to mercury thermostats in most commercial and residential applications. Moreover, the digital thermostats are programmable so they offer dollar savings by being more energy efficient. Similar alternatives exist for nearly all applications of mercury-containing switches or other process control equipment. Innovative product design can render some mercury switches obsolete.

The primary disadvantage of some alternatives is that they do not possess the proven track record of mercury-based technologies for dependability, service life, and low maintenance. Except for thermostats, the alternatives are often more expensive. Some alternatives are more complex, more difficult to manufacture, less understood, or less available.

D. Dental, Medical, and Laboratory

Because mercury readily forms alloys with other metals, it is widely used in dentistry. Dental amalgam is a mercury alloy prepared by mixing an approximately equal part of elemental liquid mercury with an alloy powder composed of silver, tin, and copper.[10] Dental amalgam has been used for over 150 years, during which time it has proven to be durable, economical, repairable, and workable.[11]

1. Alternatives

Alternatives to mercury-silver amalgam fillings include gold, ceramic, porcelain, polymers, composites and glass ionomers. Material choice is sometimes limited by the location and extent of tooth decay, the amount of stress placed on the filling, and the potential for contact with moisture during filling placement. In general, amalgam is favored over alternatives because of superior strength, durability, ease of placement, and lower cost.[12]

There are barriers to using the alternatives. Dentists overwhelmingly prefer to use amalgam, a material that has been used for decades, and is considered safe by the dental community. Composites cost up to twice as much as amalgam. The higher costs for alternative fillings are usually not covered by dental insurance, leaving the patient to pay the difference.[13]

The emphasis of most pollution prevention programs has been to help dentists to better manage mercury-containing wastes, not to foster acceptance of alternative filling materials. Since labor appears to be a major factor for the added cost of composite fillings, encouraging dentists to accept and work with composite fillings may indirectly reduce amalgam wastes.

Medical and veterinary uses of mercury include pharmaceuticals such as anesthetics, antiseptics, antineoplastic agents, antisyphilitics, cathartics, diuretics, and purgatives; disinfectants such as thimerosal and phenyl mercuric acetate; and diagnostic reagents. [14] Uses of mercury compounds in medicine have recently come under scrutiny. “The American Academy of Pediatrics and the U. S. Public Health Service have recommended that the use of vaccines containing thimerosal be reduced or eliminated and that physicians choose vaccines without the preservative whenever the option exists.” [15]

In the laboratory, mercury is used in many reagents, slide preparations, electroanalyses, and sample preservatives. [16]

E. Fungicides, Mildew~~i~~cides, and Pesticides

Mercury’s toxic properties are utilized in various biocides such as pesticides and fungicides. These include its use in paints, glues, wood preservatives, seed protectants, mold controls, maggot controls, biological specimen preparations, and tanning. [17]

“Mercury was traditionally used in agricultural chemicals as a fungicide, mildewcide, or pesticide. All food uses of mercury-containing pesticides were canceled in 1969, and all United States pesticide registrations were canceled in as of early 1995. The last four uses to be canceled were turf fungicides, mildewcides for fresh cut wood, latex paint fungicide/preservatives, and outdoor fabric treatments.” [18]

In the 1980s, the U.S. EPA asked paint manufacturers to phase out latex paints that use mercury compounds as mildewcides or preservatives. All registrations for mercury biocides used in paints were voluntarily canceled as of May 1991.[19] The U.S. EPA also banned the use of mercury in interior paint in 1990 and in exterior paint in 1991.[20]

F. Lighting

Mercury is a component in many lamps, including fluorescent, high-pressure sodium, mercury arc, metal halide, neon, and ultraviolet disinfectant lamps.[21] Today, an average fluorescent lamp contains approximately 10 to 21 milligrams of mercury.[22] In recent years, the lighting industry has attempted to reduce the amount of mercury in fluorescent lamps. However, mercury cannot be eliminated from fluorescent lamps, as it essential to its function.

1. Alternatives

Currently, the U.S. EPA/Department of Energy's Energy Star program and California Energy Commission are encouraging residents and businesses to switch from incandescent lamps to fluorescent lamps for energy savings. Fluorescent lamps use up to 75% less energy, operate at cooler temperatures, and last up to 10 times longer than incandescent lamps.[23] However, fluorescent lamps contain about 20 mg of mercury per lamp depending on the lamp's size and age. Halogen lamps, like incandescent bulbs, are a mercury-free alternative to fluorescent lamps but are 4 times less efficient[24] and operate at higher temperatures (700-1100 °F), posing an indoor fire hazard[25]. Halogen lamps and halogen infrared reflecting lamps are the preferred alternative in specific applications such as retail track lighting where compact fluorescent lights are not appropriate. However, halogen lamps should be avoided for general lighting, especially in commercial and industrial buildings since they are not as energy efficient as fluorescent and high intensity discharge (HID) lamps.

High-pressure sulfur lamps (HPSuL), and low-pressure sodium lamps (LPSL) are two outdoor lighting alternatives. The HPSuL are mercury-free but heat sensitive and require forced cooling. The technology is still new and the only marketed systems to date have been high wattage applications (≥ 1 kW)[26]. LPSLs are also a mercury-free light source that emits an orange tinged light. The poor color quality of LPSLs renders colors in shades of brown or gray and may be a poor candidate where color quality is an issue. The elemental sodium content of LPSLs is also high enough that the lamps fail hazardous waste limits for reactivity and ignitability[27].

For automobiles, halogen lamps are the industry standard but at least eight automobile manufacturers have started using HID headlamps which contain from 5 to 10 mg of mercury per headlamp[28]. The HID headlamps reportedly offer improved visibility, have a longer life span, and use less energy than the standard halogen or tungsten filament headlamps. Fluorescent lamps are also used for illuminating automotive display panels and contain approximately 5-10 mg of mercury each.

G. Household Batteries

Mercury was used in household dry-cell batteries as an active electrode and to protect battery components. For example, in alkaline and carbon-zinc batteries, mercury was used to protect the zinc cathode from oxidation and prevent the evolution of hydrogen gas. While each battery contained only an average of 0.5% mercury by weight, billions of household batteries are disposed each year. This waste stream comprised the largest source of mercury in the solid waste stream in the early 1990's. The presence of mercury in solid waste incinerator emissions sparked the movement to reduce the mercury content in household batteries.

Post-1992 household alkaline batteries and post-1991 paint contain no intentionally added mercury. Today, most consumer dry-cell batteries contain no added mercury and almost all of the mercury-containing dry cell batteries have been used and disposed. Hence, the mercury load from household batteries should continue to decline, although some consumer batteries, including mercury-zinc and many button batteries, still contain mercury.[29]

1. Alternatives

Zinc-air batteries are the major alternative for mercuric oxide batteries sold in the past, but they are not necessarily mercury free. [30] California law bans the addition of mercury to batteries for sale (Public Resources Code 15020 et.seq.). Some mercury is incidentally present in some battery types, but the content must be below 25mg. Silver oxide button cells typically contain less mercury than alkaline-manganese cells.

III. Tables

Table 4-1: Some Mercury Compounds and Uses

Mercury Compound and (Property)	Use
Metallic Mercury (Hg) (liquid and high density)	switches, thermometers, barometers, manometers, etc.
Mercurous Chloride and Mercuric Chloride ($HgCl$, $HgCl_2$) (toxic and water soluble)	various biocides including fungicides, bactericides, insecticides, (herbicides). Various pharmaceutical products.
Mercuric Oxide (HgO) (toxicity and color)	pigment in anti-fouling paints.
Mercuric Sulfide (HgS) (toxicity and color)	pigment and antibacterial in pharmaceuticals
Phenylmercuric Acetate ($C_6H_5HgCH_3COO$) (toxicity)	fungicide, herbicide, mildewcide, slimicide
Mercury Fulminate (physical sensitivity)	was used in explosives
Thimerosal ($C_9H_9HgNaO_2S$) (toxicity)	used as a preservative, now primarily in cosmetics and pharmaceuticals.

Table 4-2: Mercury Uses in Products[31]

Physical, chemical, and electrical properties:	
Instruments	barometers, hydrometers, manometers, pyrometers, sphymonometers, thermometers, thermostats
Lamps	fluorescent, high pressure sodium, mercury arc, metal halide, neon, UV disinfectant
Pivots	WWTP trickling filter arm, lighthouses
Switches	household switches, industrial switches, thermocouples, tilt (motion) switches
Electrical equipment	rectifiers, was used in batteries
Coloring	wood stain, pigments, mordant for dye
Laboratory	slide preparation (stain), electroanalysis (cathode), reagents
Toys and games	
Dental	amalgam
Toxic properties	
Pharmaceuticals	Anesthetic, antiseptic, antineoplastic agent, antisyphilitic, cathartic, diuretic, purgative
Biocides	pesticides, fungicides, mildewcides; preservatives; disinfectants such as thimerosal and phenyl mercuric acetate (PMA)

TABLE 4-3: Major Mercury-Containing Products and Alternatives*

CATEGORY	APPLICATION	POSSIBLE ALTERNATIVES
Silver amalgam	Dental fillings	Acrylic/epoxy/resin based material or gold
Lamps	Fluorescent Metal halide high pressure sodium vapor Mercury vapor ultra-violet spectral lamps Neon (all colors except red, orange and pink)	High intensity discharge. Low mercury fluorescent lights Mercury-free high-pressure sodium lamps. Incandescent lamps
Paint	Mercury-based anti-mildew agents	Non-mercury based biocides
Pigments	Color for artist paints and incorporated into some products (such as plastics)	Non-mercury based inorganic salts and compounds
Thermometers	Medical, scientific, and industrial temperature measurement	Electronic (digital), Chemical heat sensitive strip, Non-mercury liquid filled (dyed alcohol)
Thermostats	Temperature control in rooms, incubators, refrigerators etc.	Thermostat with bi-metallic strip Snap switches Electronic systems
Relays	High current/voltage lighting Power supply switching Tungsten lighting Test, calibration, measurement equipment	Mechanical and solid state relays
Switches	Airflow/fan limit control Security systems Chest freezer lid switches Fire alarm box switches Fluid level controls Pressure controls Silent light switches	Mechanical switches Magnetic dry reed switches
Flame sensor/safety valve, Main gas burners w/ standing pilot or electrical ignition pilot	Some infrared heaters Some furnaces Commercial kitchen appliances	Optic sensors
Barometers and manometers	Monitoring air pressure Flow meters and controllers for natural gas supplies	Bourdon tube Electronic gauges Non-mercury flow meters
Preservatives	Thimerosal in contact lens solutions, nasal spray, vaccines	Preservatives based on copper, tin or chromium compounds
Commercial cleaning agents-bleach, detergents, scouring powders, soaps	Cleaning and disinfecting	Mercury may be a low-level contaminant in these products (contaminant in sodium hydroxide and sulfuric acid). Select alternate brands with lower mercury levels or no detectable mercury.
Water treatment chemicals- contaminant in sodium hydroxide, sulfuric acid	pH adjustment	Lower mercury content chemicals from alternate suppliers Alternative neutralizing chemicals such as hydrochloric acid

* The alternatives outlined in Table 4-3 were gleaned from reports and web sites of other states and national agencies. Citations are included in the text that follows.

Section 4 Key Points:

- Despite the decrease in mercury consumption, significant releases to the environment are expected to continue as spent mercury-containing products are disposed.
- There is a growing list of viable alternatives for mercury products.
- Some of mercury's uses include thermometers, a variety of measurement devices, electrical devices, dentistry, medicine, lighting, and biocides.

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